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GALILEO PROBE FOREBODY THERMAL PROTECTION : BENCHMARK HEATING ENVIRONMENT CALCULATIONS

A. Balakrishnan
W. E. Nicolet

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TSI Final Report FR-80 / 1

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Prepared for
Ames Research Center
National Aeronautics and Space Administration

Contract No. NAS2-10489



**THERMAL
SCIENCES, INC.**

7
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BENCHMARK HEATING ENVIRONMENT
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FOREWORD

The work reported in this document was performed for NASA-Ames Research Center under Contract NAS2-10489. During the period of performance of this contract, Mr. John T. Howe was the NASA Technical Monitor.

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SECTION 1

INTRODUCTION

The National Aeronautics and Space Administration (NASA) is planning to launch a Jupiter Orbiter Probe during 1984. The goals of the mission, designated Galileo, are to explore the planet Jupiter and to gather clues to the origin of the solar system. The probe will carry an array of instruments for investigating the Jupiter atmosphere, including instruments to measure the atmospheric composition and perform a local radiative energy balance.

The general features of the entry into the Jovian atmosphere are set by the unique features of the planet itself. Because of its mass, Jupiter has about six times the gravity of Earth; moreover, it rotates rapidly about its axis. The probe will approach the Jovian atmosphere with an inertial velocity of 60 km/sec and enter the atmosphere in a near-equatorial plane in the direction of the planetary rotation. The relative velocities between the probe and the atmosphere will be reduced to roughly 48 km/sec, still a factor of 7.8 higher than ICBM entry into Earth's atmosphere. At the velocities projected for Jovian entry, strong shocks will envelope the probe creating a radiatively participating flowfield and yielding extremely hostile radiative and convective heating environments.

To accommodate the intense entry heating, effective thermal protection systems must be designed. The heatshield must be able to withstand the intense heating, yet be light enough to allow the design payload of scientific instruments to be carried. Carbon-phenolic has been identified as the baseline material for this mission. As earlier studies show, carbon-phenolic can provide the required thermal protection for a heatshield weight allocation of 30 to 45 percent of the probe weight. Figure 1-1 shows the candidate Galileo probe configuration.

The design of the Galileo probe heatshield is in its final stages. Because of the weight and time critical nature of the probe mission, sophisticated or benchmark prediction procedures are to be employed. It is anticipated that the results obtained from the benchmark predictions will be used directly for the sizing of the heatshield.

The analysis used in the benchmark procedure should account for all the important physical events that occur in the hypersonic flowfield. Thermal radiation is the dominant energy exchange mode for the entry conditions encountered during Jovian atmospheric entry. Radiation is emitted in the outer regions of the shock layer. The intensity of radiation strongly depends upon flight conditions, size, and shape of the shock that envelopes the body, and the model atmospheric composition of the planet. This intense radiation causes massive ablation which affects the entire flowfield over the probe. For example, it was found in previous studies that ablation products form a thin layer near the wall for laminar flows. This ablation product layer can shield the wall, in part, by absorbing a significant portion of the incident radiation. However, if the flow over the probe becomes turbulent, the eddies tend to break up the ablation product layer and mix the ablation products with the

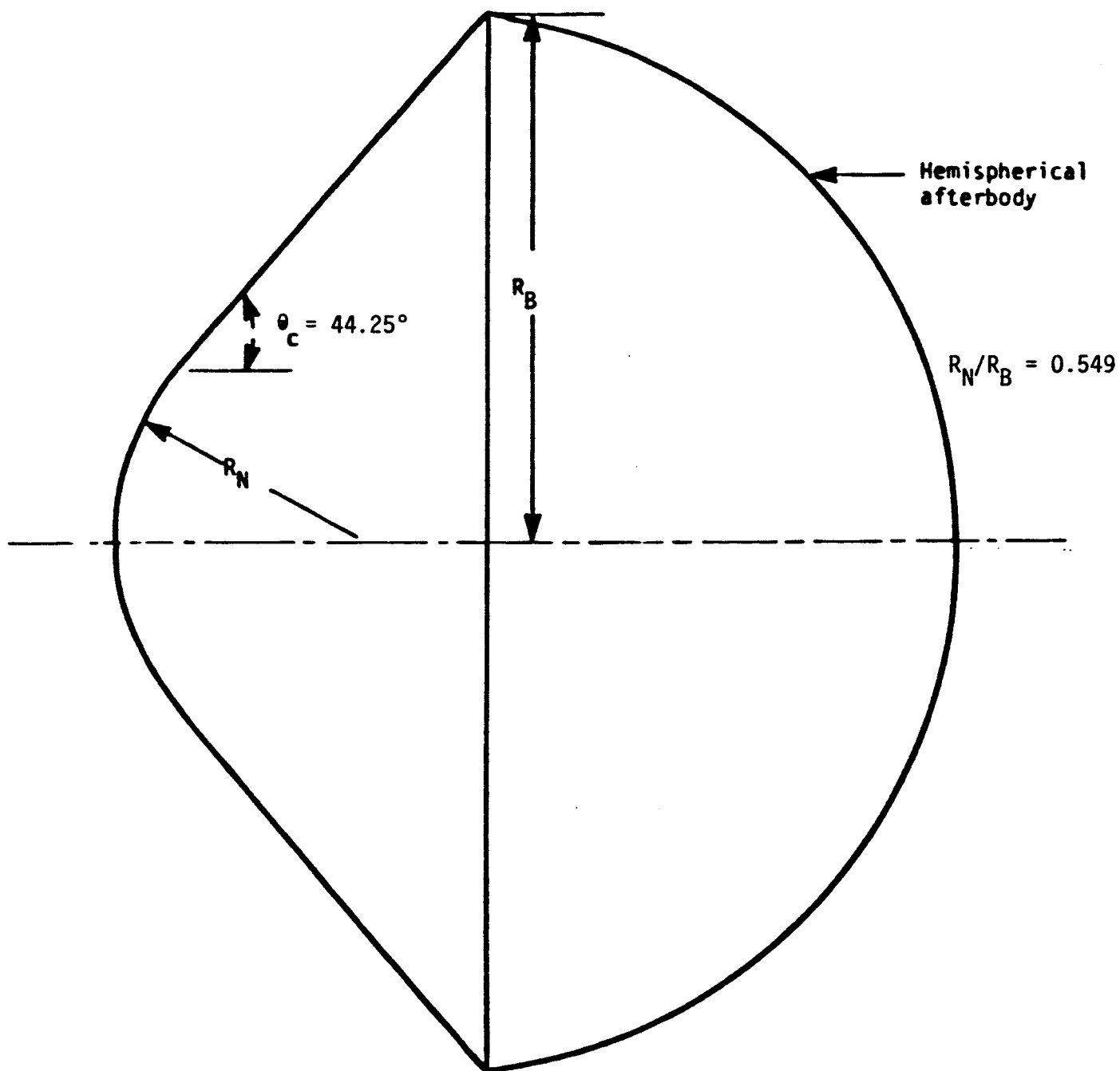


Figure 1-1. Entry Probe Configuration

environmental gases. This eliminates the attenuation of the incident radiation and increases the temperatures in the near-wall region of the mixing layer. Both effects enhance the net radiation to the wall. In addition, the combination of increasing shear and increasing standoff distance tends to increase ablation rates with distance in the flank region of the probe. This could have a severe impact on the heatshield weight.

Accurate predictions of the entry heating events have been found to require detailed modeling of the flowfield. Particular attention needs to be directed to the thermochemistry, transport, and radiative properties of the entire shock layer and how they couple to the flowfield. The currently employed approximate methods appear to have serious problems in predicting both the levels and the trends of the heating environments.

The benchmark prediction procedure to be used in the present study to solve the entry heating problem is the Radiating Shock Layer Environment (RASLE) program (References 1 and 2). It considers most of the important physical events during entry into outer planetary atmospheres. The RASLE code computes the quasi-steady radiative and convective heating environments as a function of entry trajectory conditions, probe shape, and model atmosphere. Heatshield sizing calculations are carried out at a number of specific entry conditions taken from the entry trajectory. This yields a matrix of solutions meant to define the entry heating pulse and the total mass (integrated over both time and surface area) lost from the body.

The atmospheric composition of the planet significantly influences the heating rate. From the data obtained by the latest Pioneer 10 and Pioneer 11 missions and earth-based experiments, the Jovian atmospheric

composition is determined to be made up primarily of hydrogen, secondarily helium and trace amounts of other gases. However, the precise compositions of the constituent gases are not known. Five model atmospheres were proposed by Orton (Reference 3). They were the nominal, cool-light, cool-heavy, warm-light, and warm-heavy. Entry into cool-heavy model atmosphere is the severest one. For design purposes, it is adequate to analyze entries into nominal model and cool-heavy model atmospheres.

The objective of the present study is to obtain a matrix of benchmark heating environments to the Galileo probe forebody. The matrix selected considers two probe weights (310 kg and 290 kg) and both the nominal and cool-heavy model atmospheres. For each model atmospheric entry, seven trajectory times were selected. These selected trajectory times include early, peak, post-peak, and late times in the heating pulse. The 310 kg probe was taken as the baseline configuration. Two additional solutions were obtained for the 290 kg probe to allow comparison to be made with the solutions obtained by other investigators.

The following sections present the results of this study. In Section 2, the results of the trajectory calculation are given. Wall heating and ablation rates to the forebody are presented in Section 3 for the nominal model and Section 4 contains the results for the cool-heavy model atmospheric entry.

SECTION 2

ENTRY TRAJECTORY CALCULATIONS

The benchmark calculation procedure, RASLE code, needs as input the local value of freestream velocity and the corresponding density. These trajectory properties are calculated using a trajectory code. The details of the trajectory calculation procedure were described in References 4 and 5, and are not given here. Only a brief summary is given below.

The trajectory calculation scheme estimates the local value of freestream quantities such as velocity, density, and altitude as a function of entry time. The governing equations of motion are integrated using a fourth-order Runge Kutta method. The formulation considers the gravitational effects of the planet, the angular rotation of the planet, and the nonspherical shape of the planet. However, the probe shape and the associated ballistic coefficient are assumed to be invariant during the entry.

The trajectory code uses input tables of altitude versus pressure, temperature, and density. Tables of these data were supplied to us by NASA/Ames for the Orton (revised) model, and used to construct the input tables needed for the trajectory code. The NASA/Ames-supplied atmospheric tables for nominal and cool-heavy models are included in Appendix A.

Probe configuration and entry parameters were also supplied by NASA/Ames. Table 2-1 summarizes these data. Note that the present study

addresses a 310 kg baseline probe. The probe has a conical forebody with a 44.25 degree half cone angle and a spherically blunted nose cap with a radius of 0.352 m. This particular probe is heavier than earlier probes considered by NASA/Ames.

Utilizing the information provided in Table 2-1 and Appendix A, the trajectory code outlined in References 4 and 5 was used to compute the variation of freestream quantities with entry time. Figures 2-1 and 2-2 show the density vs velocity relations for the nominal and cool-heavy model atmospheres, respectively.

The figures and Appendix A show that the relative entry velocity is not affected until the probe descends to an altitude of about 250 km. Significant deceleration of the probe occurs only in the altitude region between 150 to 50 km range.

Two matrices of trajectory points were selected from the computed trajectories. One matrix represents the nominal model atmosphere, the other matrix represents the cool-heavy model atmosphere. Each matrix consisted of seven velocity density combinations to be used as input to the RASLE code for subsequent evaluation of the heating environments. In addition, two trajectory points for a lighter probe ($m = 290$ kg) were also considered. The trajectory calculations for the lighter probe were performed by NASA/Langley and supplied to us by NASA/Ames.

Table 2-1. Probe Configuration and Entry Parameters for Galileo
Probe Jupiter Entry Computations

Atmosphere

Orton models, revised August 10, 1979
Nominal and cool-heavy

Probe Configuration

Mass:	310 kg
Nose radius:	0.352 m
Base radius:	0.641 m
Half cone angle:	44.25°
Drag coefficient:	1.05
Ballistic coefficient:	228.72 kg/m ²

Entry Parameters

Altitude:	450 km
Relative velocity:	48.2 km/s
Relative entry angle:	-8.6°
Entry latitude:	+3.4°
Relative azimuth:	70.3°

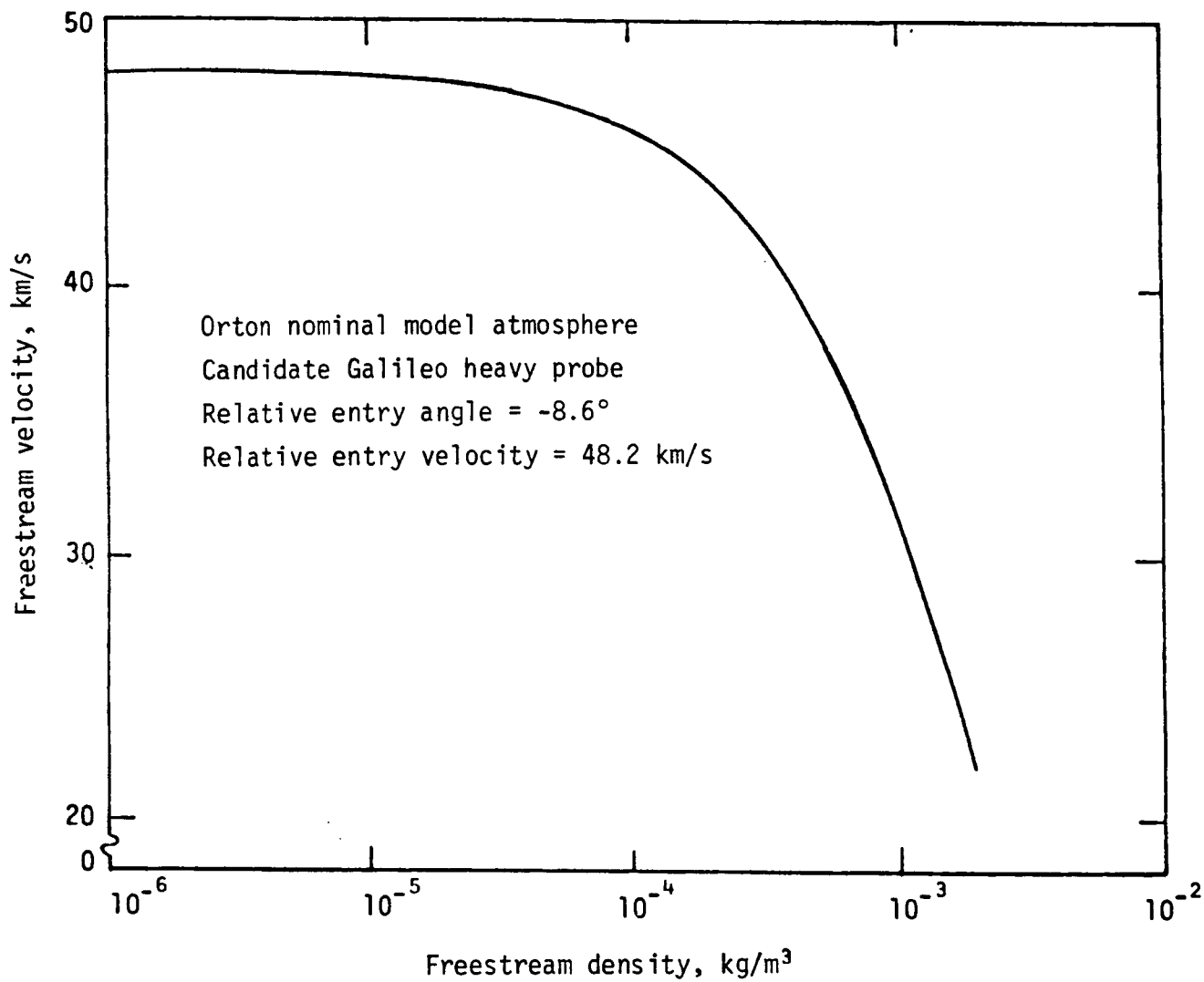


Figure 2-1. Variation of Freestream Velocity With Density
for Orton Nominal Model Atmosphere

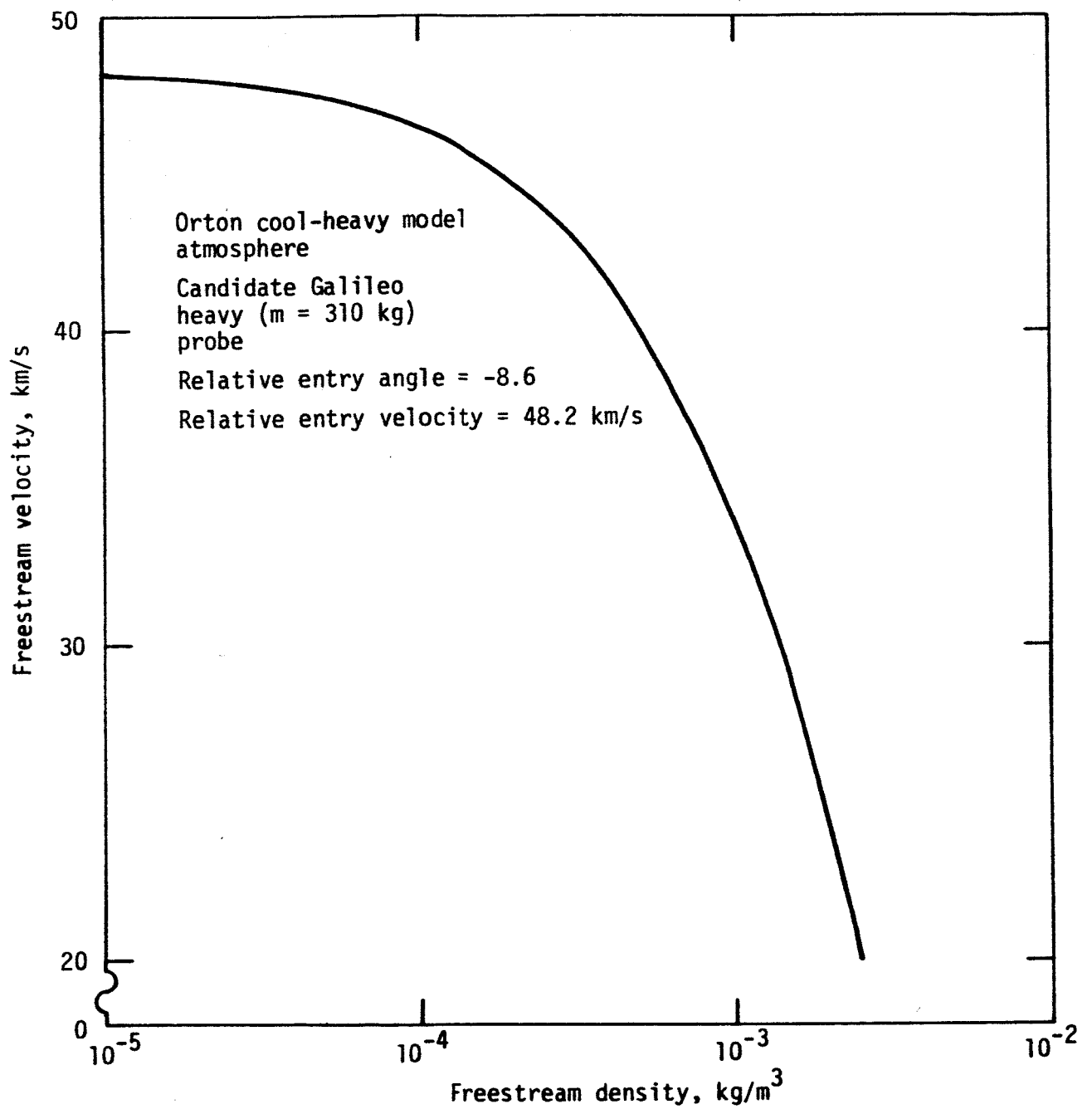


Figure 2-2. Computed Entry Trajectory for Orton Cool-Heavy Model Atmosphere

SECTION 3

HEATING ENVIRONMENTS FOR NOMINAL MODEL ATMOSPHERIC ENTRY

The analysis used in developing the RASLE code considers most of the important physical events that occur during planetary entry. The detailed development of the RASLE code was described elsewhere (References 1 and 2) and is not repeated here. In the following subsections, brief discussions of the physics considered, numerical method used, and the method of finding converged solutions are presented. Results obtained for all of the nominal model atmospheric entry cases are also given.

3.1 PHYSICAL MECHANISMS INCLUDED IN THE FORMULATION OF RASLE CODE

The physical events that occur during planetary entry are modeled through governing equations. The governing equations include mass, momentum, and energy transfer. For each of the physical mechanisms, needed properties for the mixture of species are evaluated in detail. An overview of the physics considered in the RASLE code is outlined below:

- Governing equations

The conservation equations are written for a steady state, thin shock layer of a chemically reacting and radiatively participating gas mixture. Terms representing the effect of probe body curvature, nonsimilar terms, and radiation coupling

are also included. The governing equations employ the boundary layer approximation and hence the pressure in the wall normal direction is assumed to be constant.

- Thermodynamics and chemistry

Local thermodynamic equilibrium (LTE) is assumed to exist everywhere. From specified values of static enthalpy, static pressure, and elemental mass fractions, an equilibrium chemistry procedure computes the thermodynamic properties such as density, temperature, specie mole fractions, and mean molecular weight by integrating the specific heat. Data on specific heats for many species, in the temperature range (300° to $6,000^{\circ}\text{K}$), are tabulated in JANNAF thermochemical tables (Ref. 6).

- Molecular transport properties

Real gas transport properties are calculated based on Yos's modified first order Chapman-Enskog theory (Ref. 7). Yos gives mixing rules for calculating viscosity, thermal conductivity, and binary diffusion coefficients. The needed inputs are the collision integrals for each pair of species. Available data on collision integrals were curve fitted and are used directly for calculating the momentum and energy exchange during collisions between important species. The binary diffusion approximation is also used.

- Turbulent transport model

Mixing length models are used to describe the turbulence. The turbulent layer is divided into two regions — inner (wall law) and outer (wake law). In the inner region, the wall law

equation allows growth of the mixing length as a function of the distance from the wall and local shear. This model allows the effect of blowing to be introduced into the turbulence model. In the outer region, the flow behaves like a free mixing layer, with the mixing length proportional to its overall width.

- Radiation properties and transport

A detailed, rather than a multiband, properties model is used. Accordingly, each radiative transition is considered individually. Molecular band systems, continuum transitions, and atomic and ionic lines are included for the radiating species of the C-H-O-N-Si-He elemental system. The spectrum is divided into a large number of intervals. At each of the selected spectral points, the spectral fluxes are calculated using the plane-parallel slab approximation. The total flux values are obtained by integrating the spectral fluxes.

- Shock shape

The predictive procedure uses shock front radius of curvature; therefore, the shock shape is to be specified a priori. From the input shock shape, a body shape is computed. In this respect, the predictive procedure can be considered as an inverse method. The shock shape is specified with the use of the Falanga and Olstad correlation (Reference 8). However, the calculated body shape may not correspond to the exact body shape. The shock shape is iterated until the actual body shape is obtained. In practice,

the shock shape correlation developed by Falanga and Olstad has proven accurate enough to allow satisfactory solutions to be obtained in two or three iterations.

3.2 METHOD OF SOLUTION

The conservation equations are nondimensionalized before attempting to solve them. Combination of the Shvab-Zeldovich transformation and the binary diffusion approximation reduce the set of diffusion equations to a single equation. The Levy-Lees variables are used instead of the primitive independent variables. Introduction of the stream function eliminates the global continuity equation. The nodes are selected in the wall normal direction. Interpolation relations are used to integrate the equations between the nodes. This operation reduces the conservation equations from partial-differential-integral equations to nonlinear algebraic relations between the various flowfield variables evaluated at each of the nodal points. A set of iterative equations, based on the multidimensional Newton-Raphson method is defined to solve the algebraic equations.

First, a solution at the stagnation point is found for a given freestream velocity and density and an assumed shock shape about the body. Solutions are obtained at off-stagnation points by marching off the stagnation point using the stagnation point solution as a first guess. Small marching steps are usually needed near the stagnation point. The solution procedure is continued until the required body point distance is reached. The computed body shape is compared with the actual body shape. If significant differences exist between the two, the solution is repeated, iterating on shock shape.

Convergence is usually obtained within three to five iterations provided the previous upstream solution is used as a first guess and the flowfield physics is changing gradually in the streamwise direction. Sudden large changes in the flowfield physics, such as transition or discontinuous change in the curvature of the body, are found to cause convergence problems. Such problems are handled by introducing the changes to the flowfield physics gradually, across small transition regions defined in the streamwise direction. This causes the flowfield profiles to change in a correspondingly gradual manner, thus allowing solutions to be obtained.

3.3 RESULTS AND DISCUSSION FOR HEAVY PROBE ($m = 310$ kg)

Computed heating environments for a total of seven nominal entry conditions are presented. Table 3-1 shows the matrix of cases considered for the heavy probe. Appendix B contains the RASLE calculated results for all the seven cases. The solutions obtained assume that transition occurs in the immediate vicinity of stagnation point. For all cases considered, the flow was fully turbulent at a distance $s/R_N \sim 0.1$. The heating rates and ablation rates tabulated in Appendix B assume a wall response corresponding to steady-state ablation conditions. In the present calculation, it is assumed that wall emissivity and absorptivity are both equal to 1.

Figures 3-1 and 3-2 show the calculated results at the stagnation point. Figure 3-1 shows the variation of radiative heating rate and ablation rate with trajectory time. Figure 3-2 shows the variation of convective heating rate and pressure with time. Similar results for the flank region ($s/R_N = 2.1$) are given in Figures 3-3 and 3-4.

Table 3-1. Selected Matrix of Cases for Nominal Model Atmosphere

Case	Time (sec)	Velocity, v_{∞} (km/s)	Density, ρ_{∞} (kg/m ³)	$\rho_{\infty} v_{\infty}^3 / \rho_{\infty} v_{\infty}^3 _{\max}$
1	43.0	46.58	8.059-5*	0.25
2	47.0	44.47	1.869-4	0.50
3	49.2	42.30	3.046-4	0.70
4	50.3	40.87	3.861-4	0.80
5	51.5	39.04	4.966-4	0.90
6	54.1	34.12	8.262-4	1.0
7	56.7	28.37	1.290-3	0.90

*8.059-5 = 8.059×10^{-5}

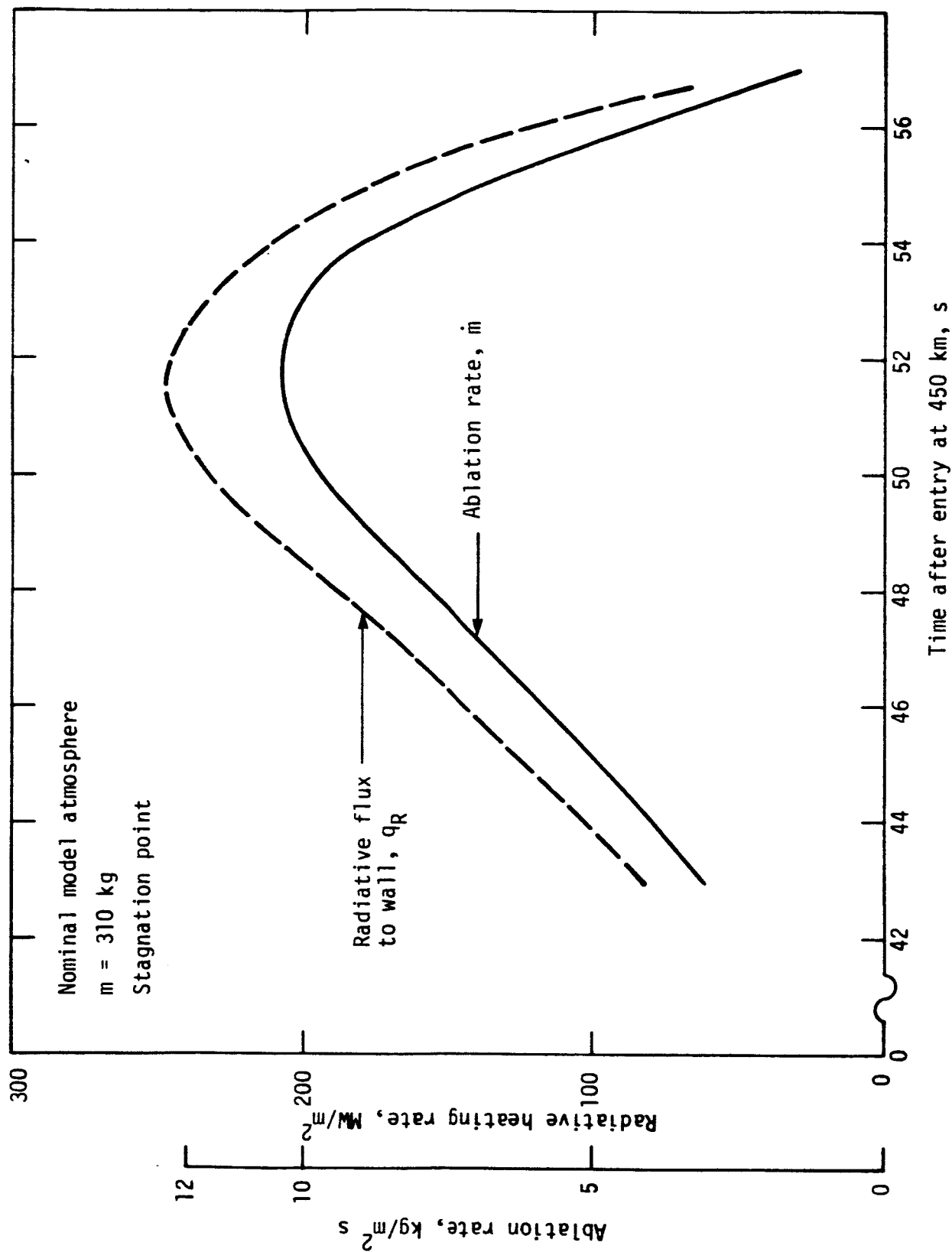


Figure 3-1. Time History of Ablation Rate and Radiative Heating Rate at the Stagnation Point for Nominal Model Atmosphere

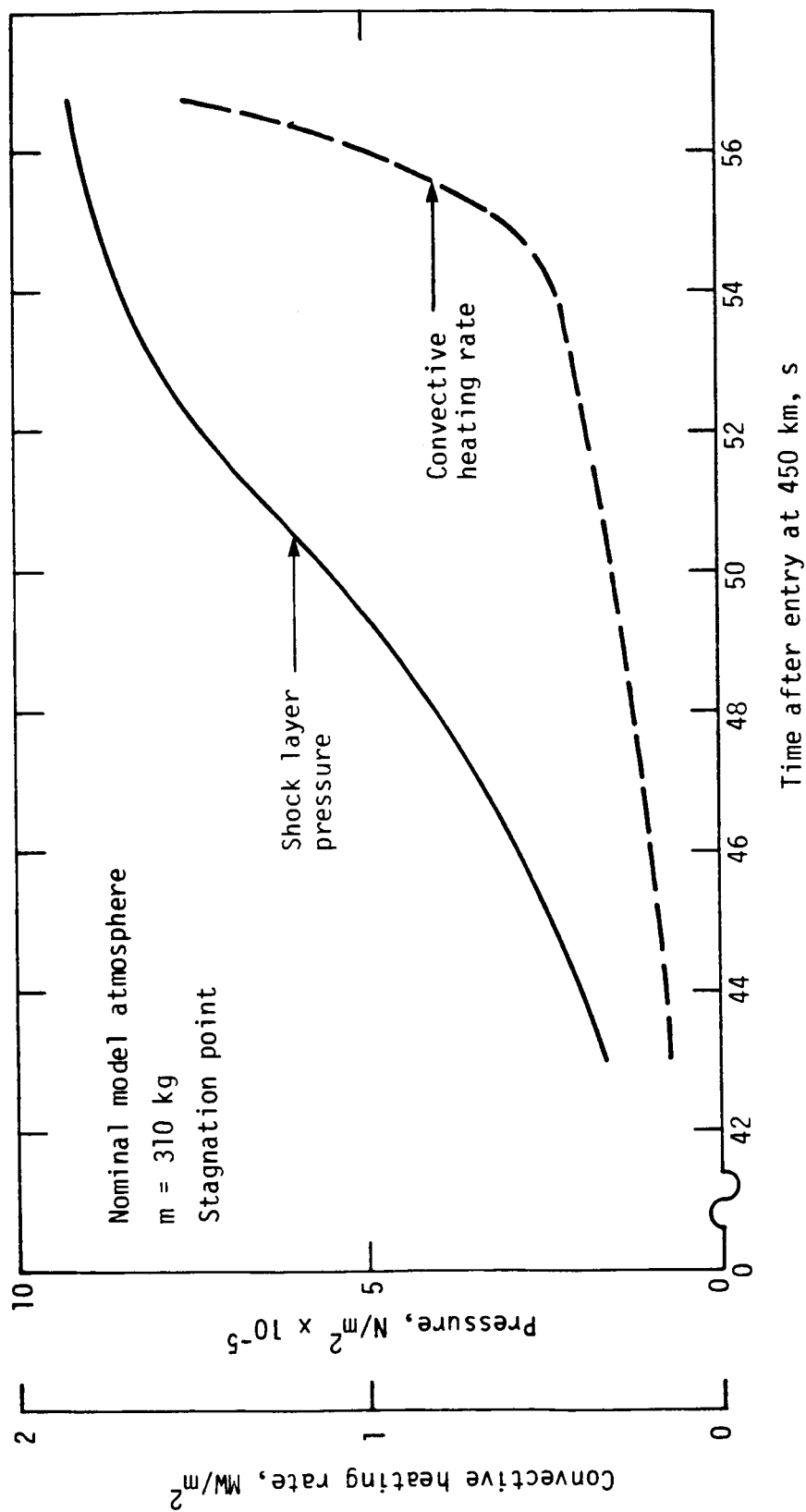


Figure 3-2. Time History of Pressure and Convective Heating Rate at the Stagnation Point for Nominal Model Atmosphere

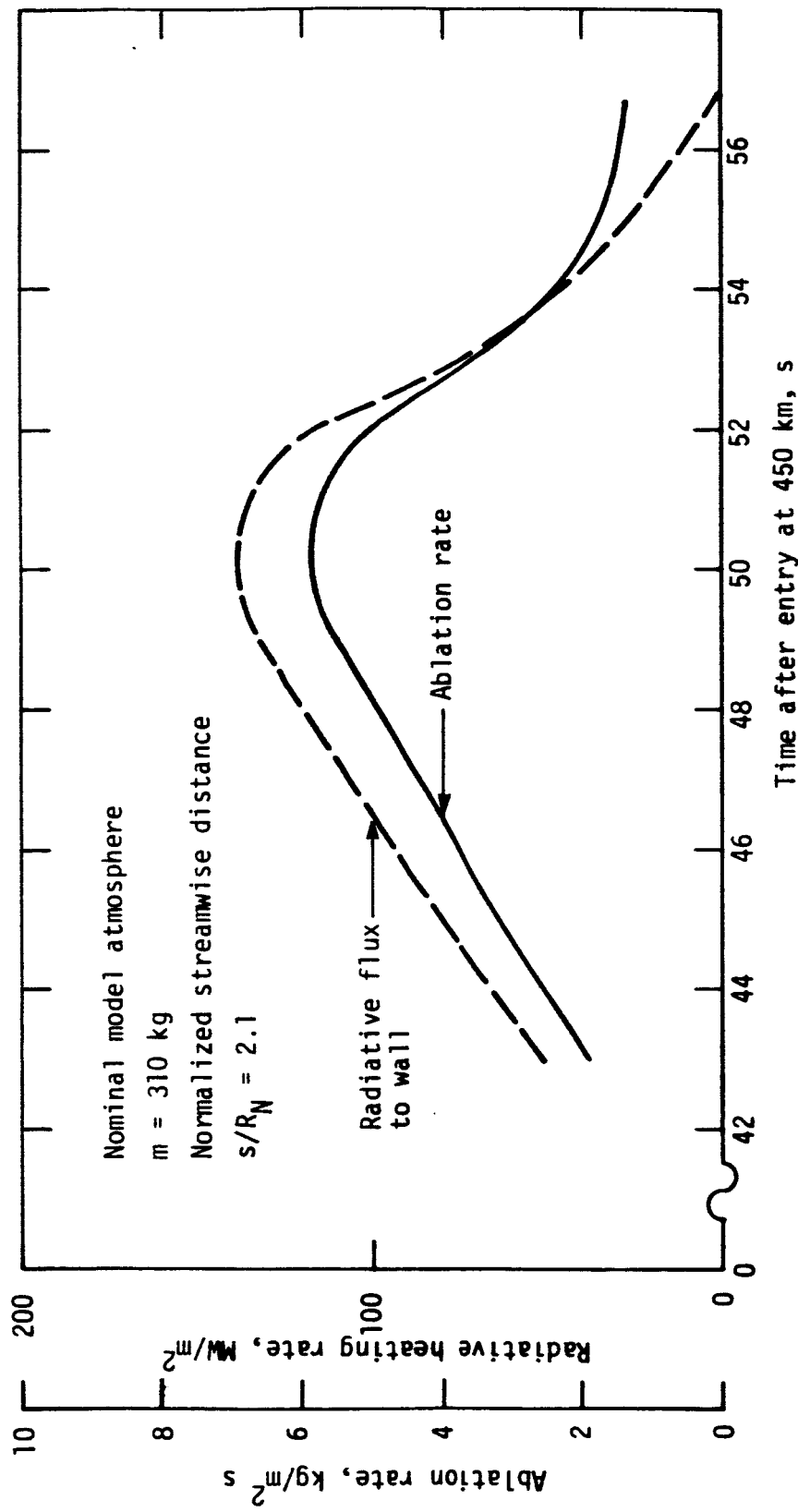


Figure 3-3. Time History of Ablation Rate and Radiative Heating Rate at Flank ($s/R_N = 2.1$)

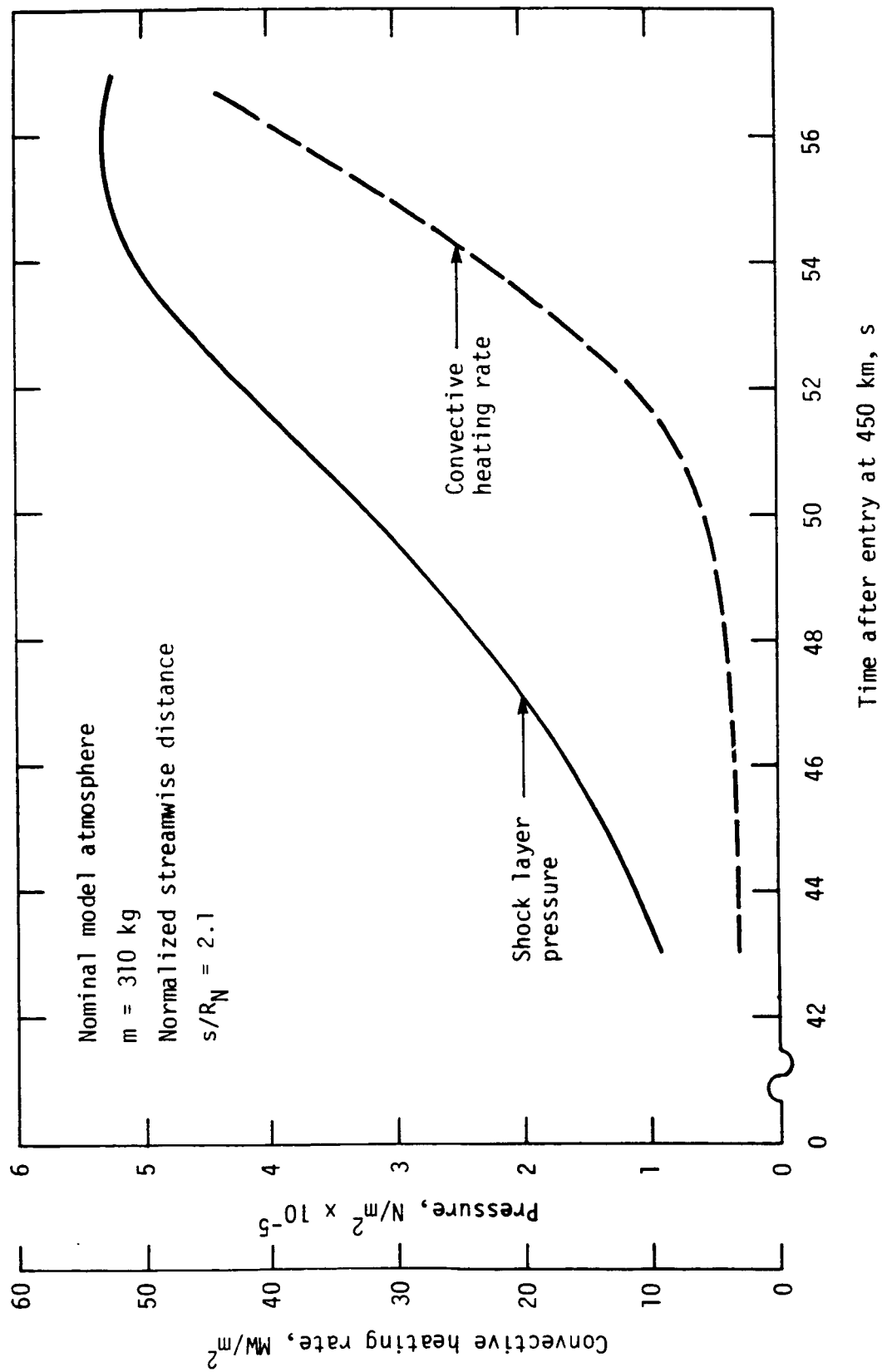


Figure 3-4. Time History of Pressure and Convective Heating Rate at Flank ($s/R_N = 2.1$)

At the stagnation point, the heating is dominated by radiation; therefore, the ablation rate follows the radiative heat flux. From Figure 3-1, it can be seen that the total heating pulse is roughly 15 seconds. After the peak heating time, the radiative heating falls off rapidly. Figure 3-2 shows that the convective heating rate follows the pressure. However, due to the massive blowing, the convective heating rate levels are reduced. Note that after the peak heating, the blowing rate decreases, and hence the convective heating rate is not reduced significantly.

Velocity profiles at two trajectory times are presented in Figures 3-5 and 3-6 to illustrate the breakup of the ablation product layer. Figure 3-5 corresponds to the peak heating time in the trajectory. The velocity profiles for various s/R_N locations are shown. At the stagnation point, the flow is laminar; however, due to blowing, a fully blown-off ablation layer is seen. As the solution marches around the body, the flow becomes fully turbulent, the eddies cause reattachment at the wall. Also, vigorous mixing between the environmental gas and ablation products occurs. As the solution moves onto the flank, say $s/R_N = 2.0$, the ablation layer is considerably thinner. Due to turbulent mixing, the ablation layer is highly mixed and heated. Thus, the ablation layer is no longer effective as a radiation shield. Indeed, it has been shown that the radiation emission from the mixing layer can enhance the flux incident upon the wall under some circumstances.

In contrast, at late entry times the blowing and radiative heating levels fall off rapidly. As seen in Figure 3-6, the velocity profiles,

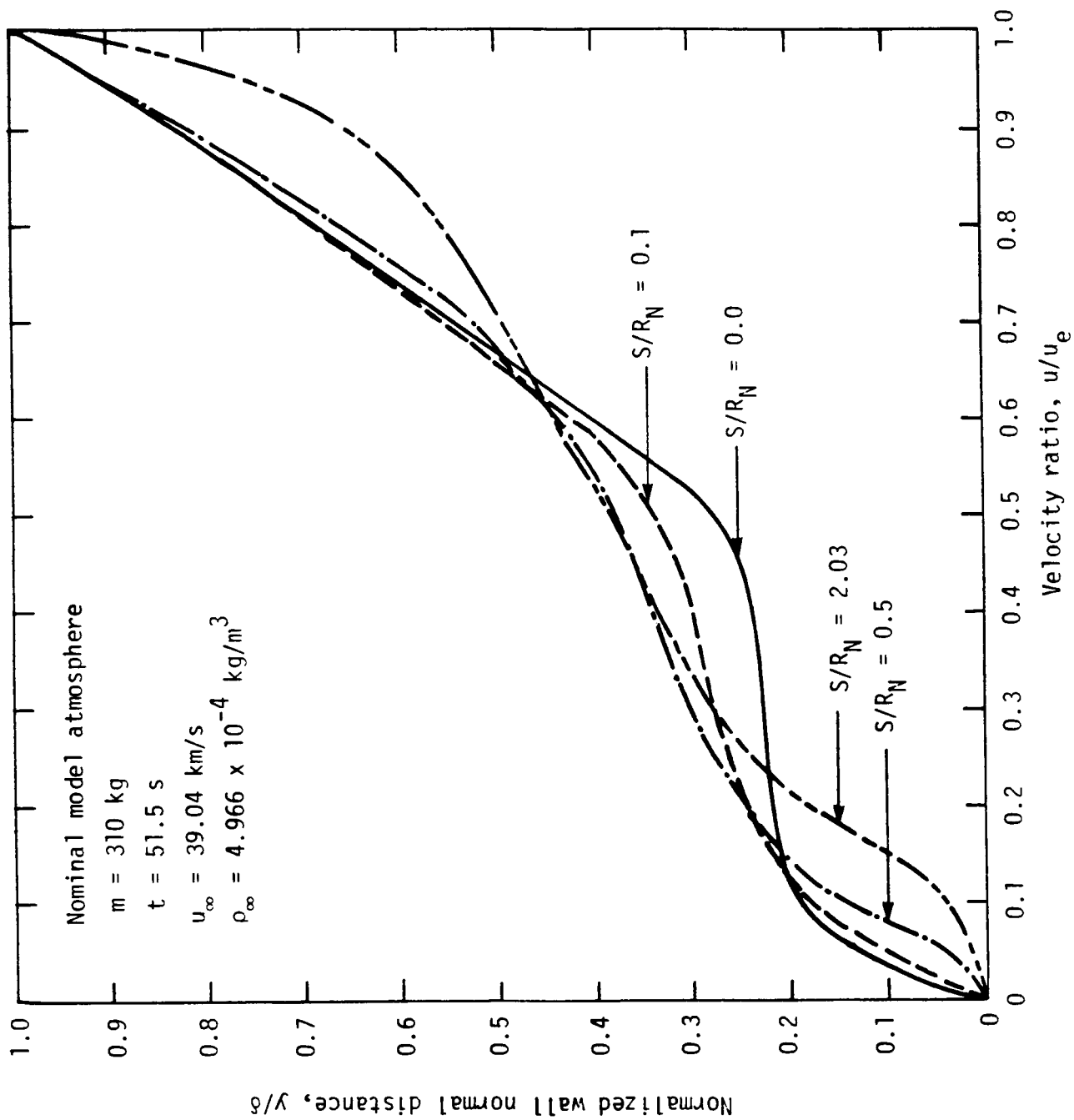


Figure 3-5. Velocity Profiles for Trajectory Time $t = 51.5 \text{ sec}$

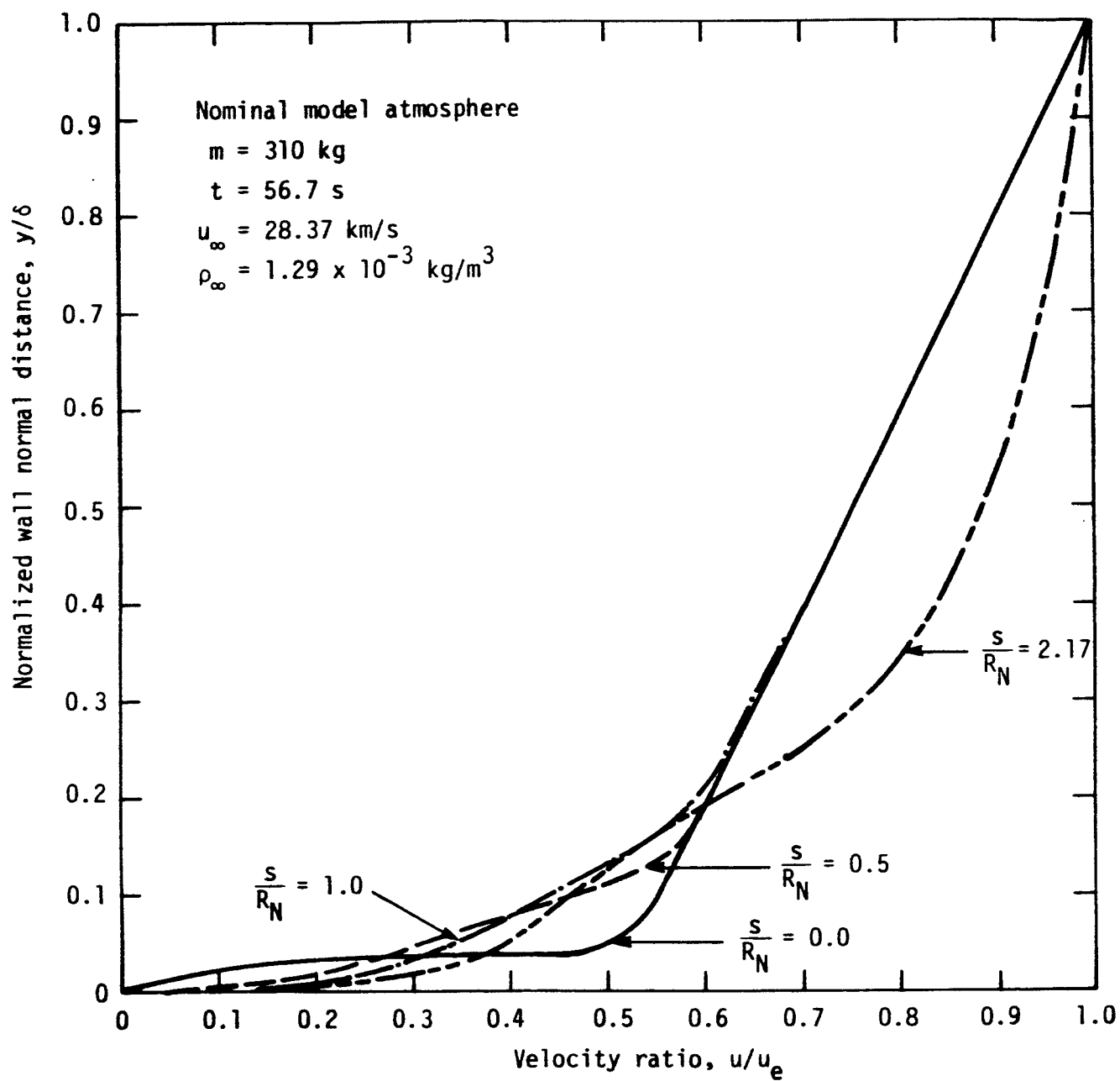


Figure 3-6. Velocity Profiles for Trajectory Time $t = 56.7 \text{ sec}$

except at the stagnation point, are all attached and look like the usual turbulent boundary layer profiles. Breakup of the ablation layer is not a factor here.

The computed ablation rate at each streamwise station can be integrated to obtain the mass loss rate. Figure 3-7 shows the time history of mass loss rate. The area under the curve is the total mass loss during the entry. For this particular entry, total mass loss is about 101 kg. Also shown in Figure 3-7 are the mass loss rates obtained from the results provided by COLTS (Reference 9). Results at early and late times agree well; however, near the peak heating the difference is about 18 percent. Explanation for the difference is presented in Section 3.4.

3.4 RESULTS AND DISCUSSION FOR LIGHT PROBE ($m = 290$ kg)

Heating environments for a light probe entering the nominal model atmosphere are presented in this section. The results calculated by the RASLE code and COLTS are compared. Table 3-2 presents the two times in the trajectory that were considered. For this particular probe, trajectory information were provided to us by NASA-Ames.

Calculated results are summarized in Tables a and b of Appendix C. Figures 3-8 and 3-9 compare the radiative heat fluxes for both the entry times. Results indicate overall agreement. In the flank region, RASLE is consistently higher. In the spherical segment of the probe, the agreement is good. At the stagnation point, RASLE assumes the flow is laminar. However, COLTS allows propagation of turbulence effects from the transition location upstream to the stagnation point. Therefore, results by COLTS at the stagnation point are consistently high. A rather large recompression is felt by RASLE at the sphere-cone juncture. This may be

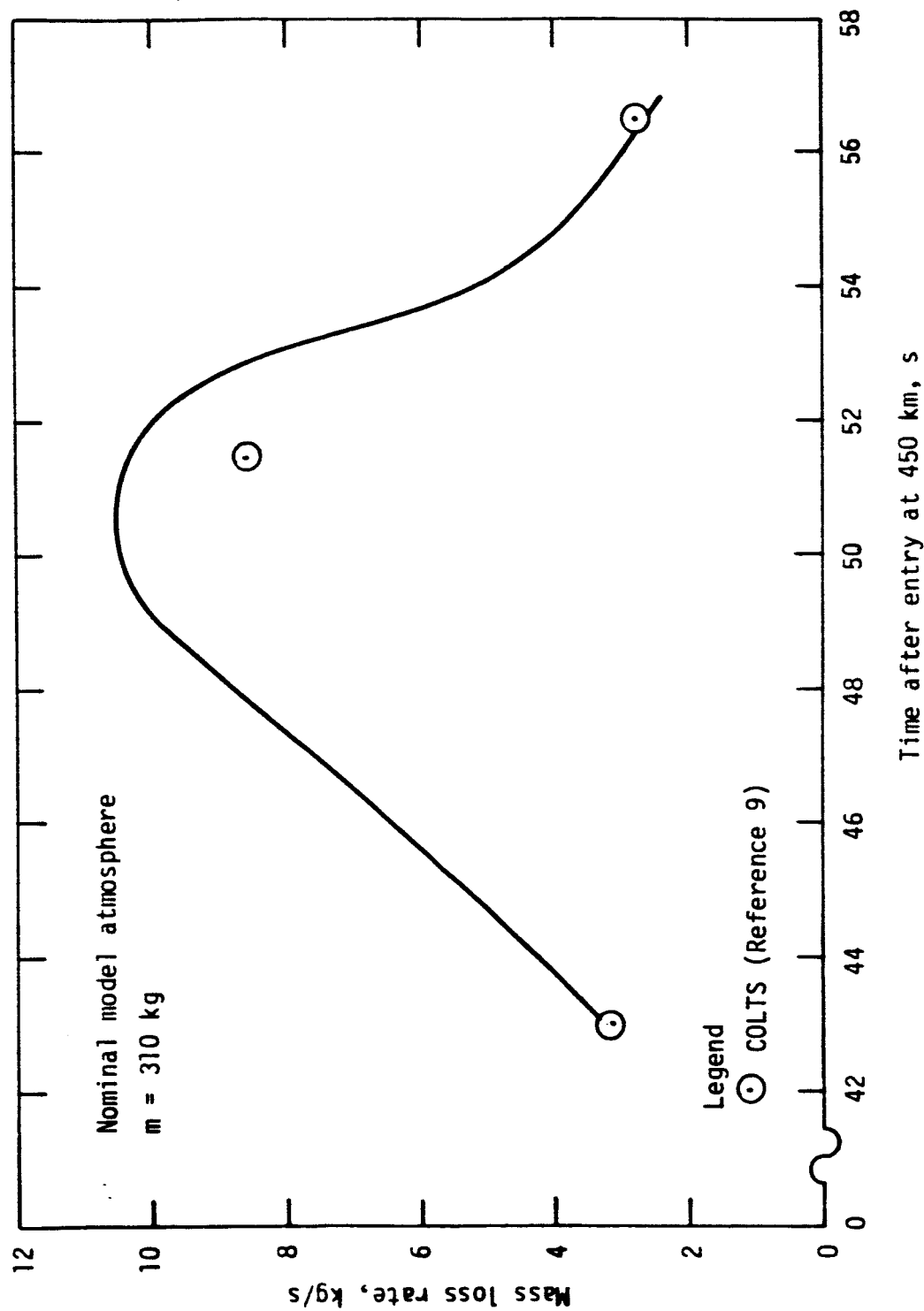


Figure 3-7. Mass Loss Rate for Nominal Model Atmosphere

Table 3-2. Matrix of Cases Considered for Light Probe Entry

$m = 290 \text{ kg}$
Nominal Model Atmosphere

Case	Time, t s	Velocity, v_{∞} km/s	Density, ρ_{∞} kg/m ³
1	45.75	44.22	2.03×10^{-4}
2	49.5	39.53	4.74×10^{-4}

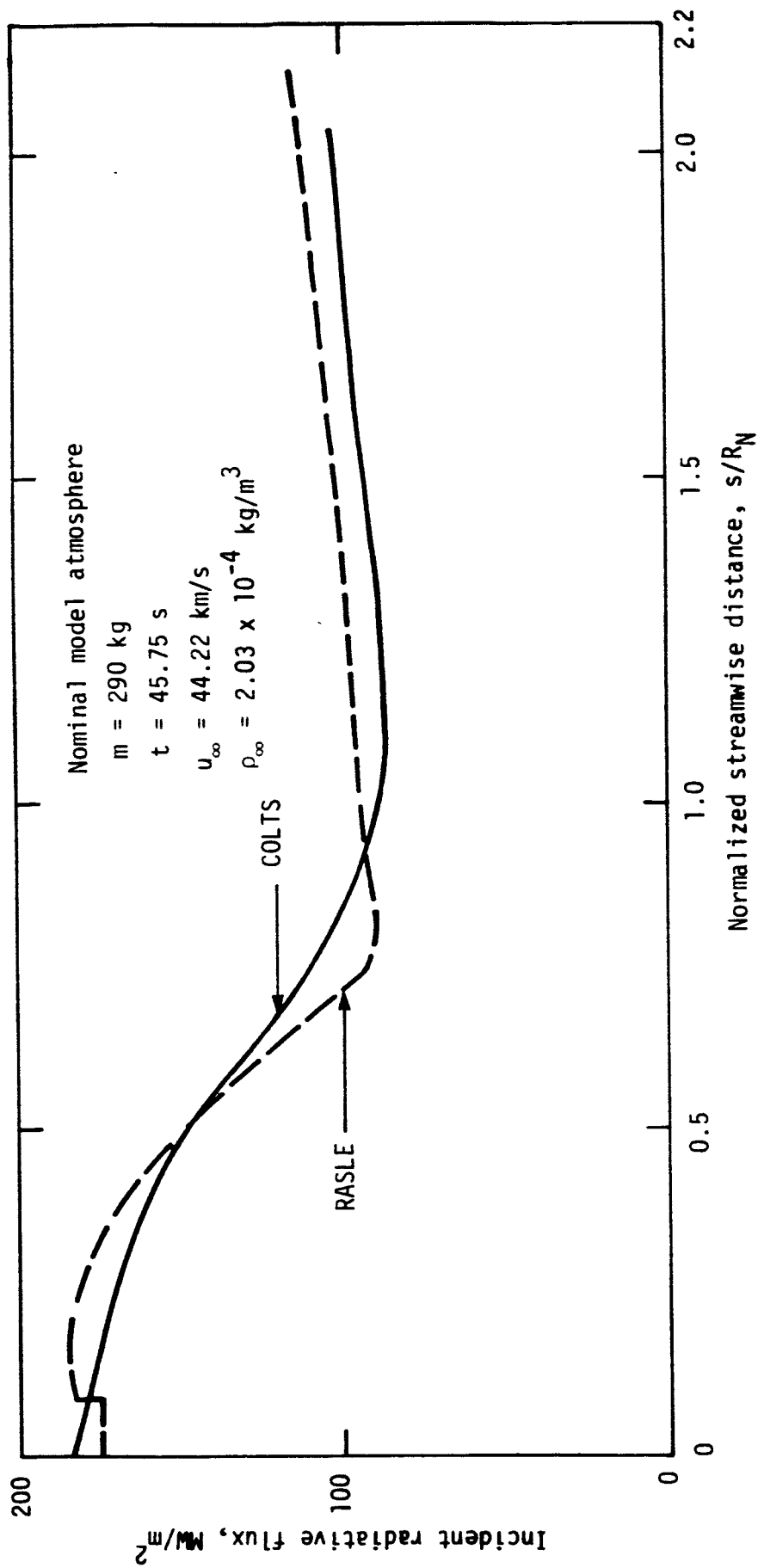


Figure 3-8. Comparison of Radiative Flux Between RASLE and COLTS at $t = 45.75 \text{ sec}$

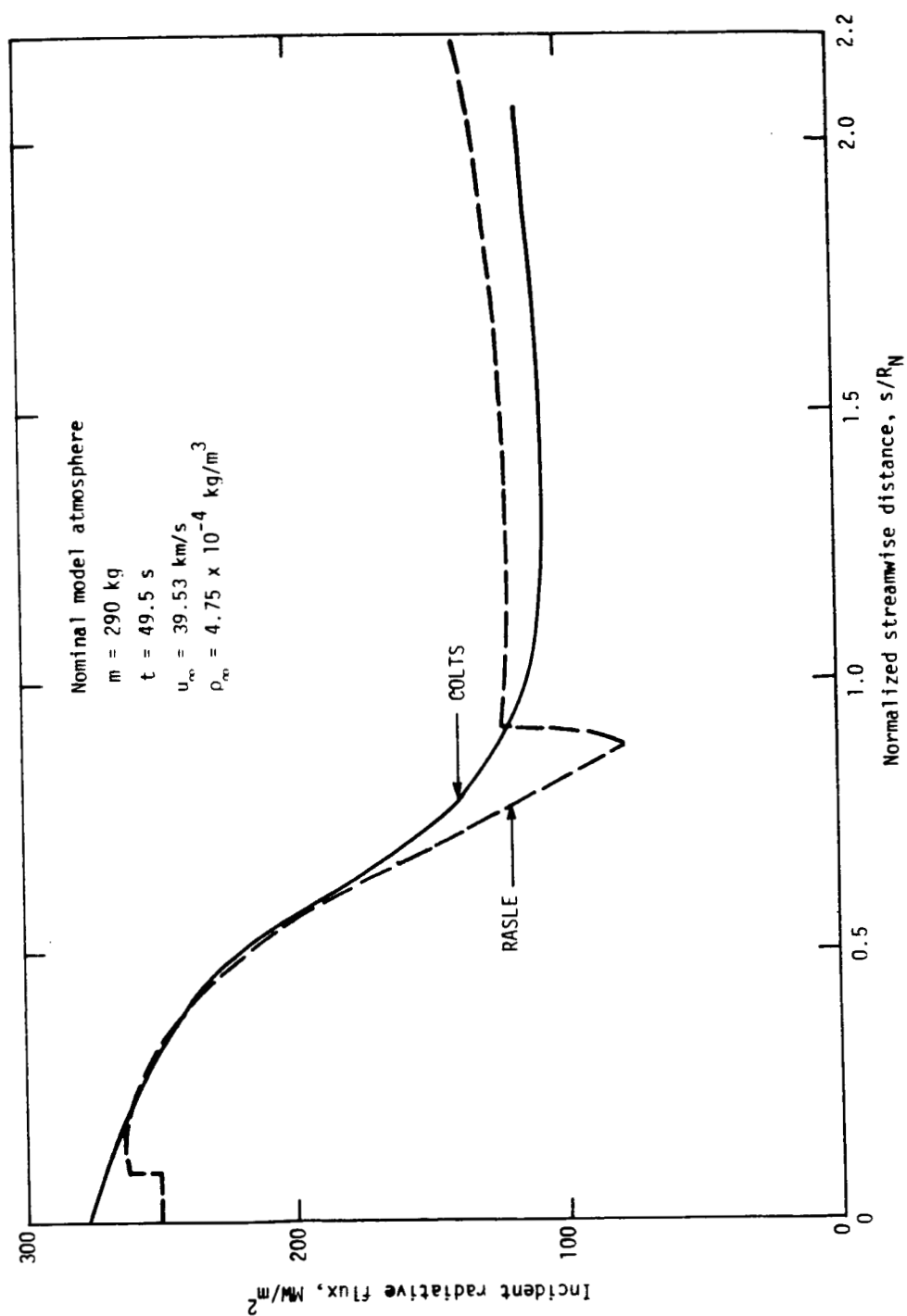


Figure 3-9. Comparison of Radiative Flux Between RASLE and COLTS at $t = 49.5 \text{ sec}$

associated with the discontinuity in curvature and the inability of the inverse numerical method to resolve it. Similar trend was observed by Moss (Reference 10) in his earlier investigations. A detailed comparison between the two codes was not made. However, Menees (Reference 11) performed such a detailed comparison between the two codes for a lighter probe ($m = 242$ kg) and also found overall agreement in the predictions.

SECTION 4

AEROTHERMAL ENVIRONMENT FOR COOL-HEAVY MODEL ATMOSPHERIC ENTRY

Benchmark solutions for nominal model atmospheric entry were presented in Section 3. In this section, calculated results for the cool-heavy model atmospheric entry are presented. Flowfield calculations for entry into the cool-heavy model atmosphere are needed, since the heating environments are very severe and may represent the design condition. It is of interest to know the heating rates, the mass loss rate, and total mass loss. With this information and comparing with the results available for nominal model atmospheric entry, one can determine the survivability of the probe if the atmosphere during entry were found to be closer to cool-heavy model.

For this model atmosphere, seven benchmark solutions were obtained. The freestream conditions for the selected matrix are listed in Table 4-1. The RASLE code computed heating environments for all the seven cases are summarized in Appendix D. Comparing the tables in Appendices B and D, it is found that radiation heating rates are about 60 percent higher than the corresponding heating rates for entry into nominal atmosphere. Also, at the flank regions, the cool-heavy heating rates are higher by a factor than the heating rates for the nominal case. This intense heating causes large mass loss rates. The mass loss rates for both the model atmospheres are shown in Figure 4-1. As shown, entry into

Table 4-1. Selected Matrix of Cases for Cool-Heavy Model Atmosphere

Case	Time (sec)	Velocity, v_{∞} (km/s)	Density, ρ_{∞} (kg/m ³)	$\frac{\rho_{\infty} v_{\infty}^3}{\rho_{\infty} v_{\infty}^3 _{\max}}$
1	47.2	46.65	9.450-5	0.25
2	50.3	44.57	2.177-4	0.50
3	52.1	42.50	3.478-4	0.70
4	53.0	41.16	4.362-4	0.80
5	54.1	39.22	5.699-4	0.90
6	56.3	34.42	9.353-4	1.00
7	58.3	28.81	1.439-3	0.90

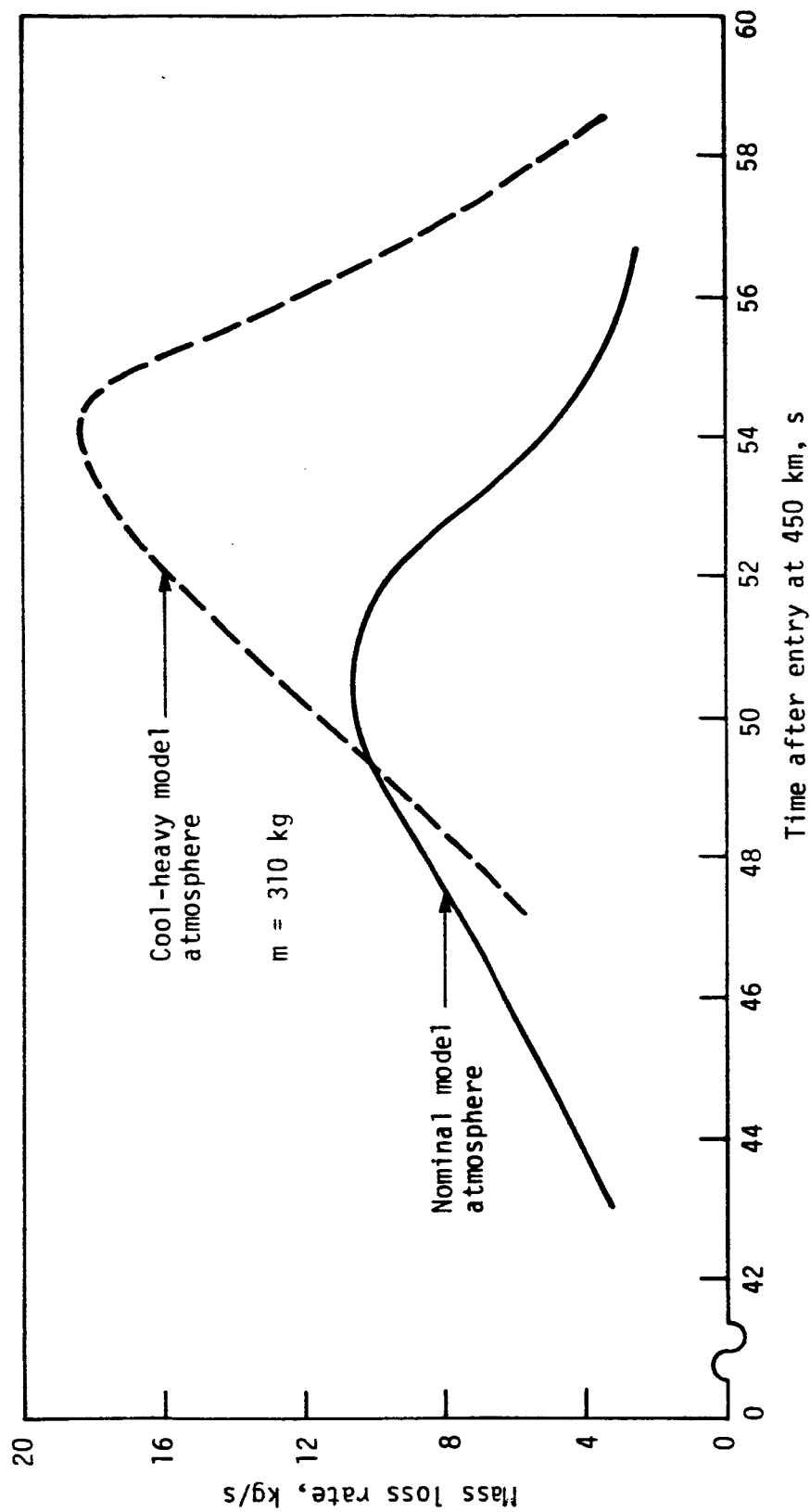


Figure 4-1. Comparison of Mass Loss Rates for Nominal and Cool-Heavy Model Atmospheres

cool-heavy model atmosphere causes mass loss rates as high as 18 kg/sec.

The area under both the curves are found to be as follows:

Nominal model: 101 kg

Cool-heavy model: 146 kg

Temperature profiles in the shock layer are shown in Figure 4-2 at a selected streamwise distance for three entry times. The figure illustrates the effect of vortical or entropy layer. The entropy layer causes the temperature profile to reach a maximum in between the wall and the shock. The effect was seen more pronounced for the late time at $t = 58.5$ sec. For that particular entry time, the peak in temperature was at a distance of 20 percent of shock standoff distance. The peak shock layer temperature was at 9600°K compared to a temperature at the shock front of 5800K . Such a nonuniformity in the shock layer can only be found with the use of benchmark solution procedures and cannot be predicted with approximate methods in current use.

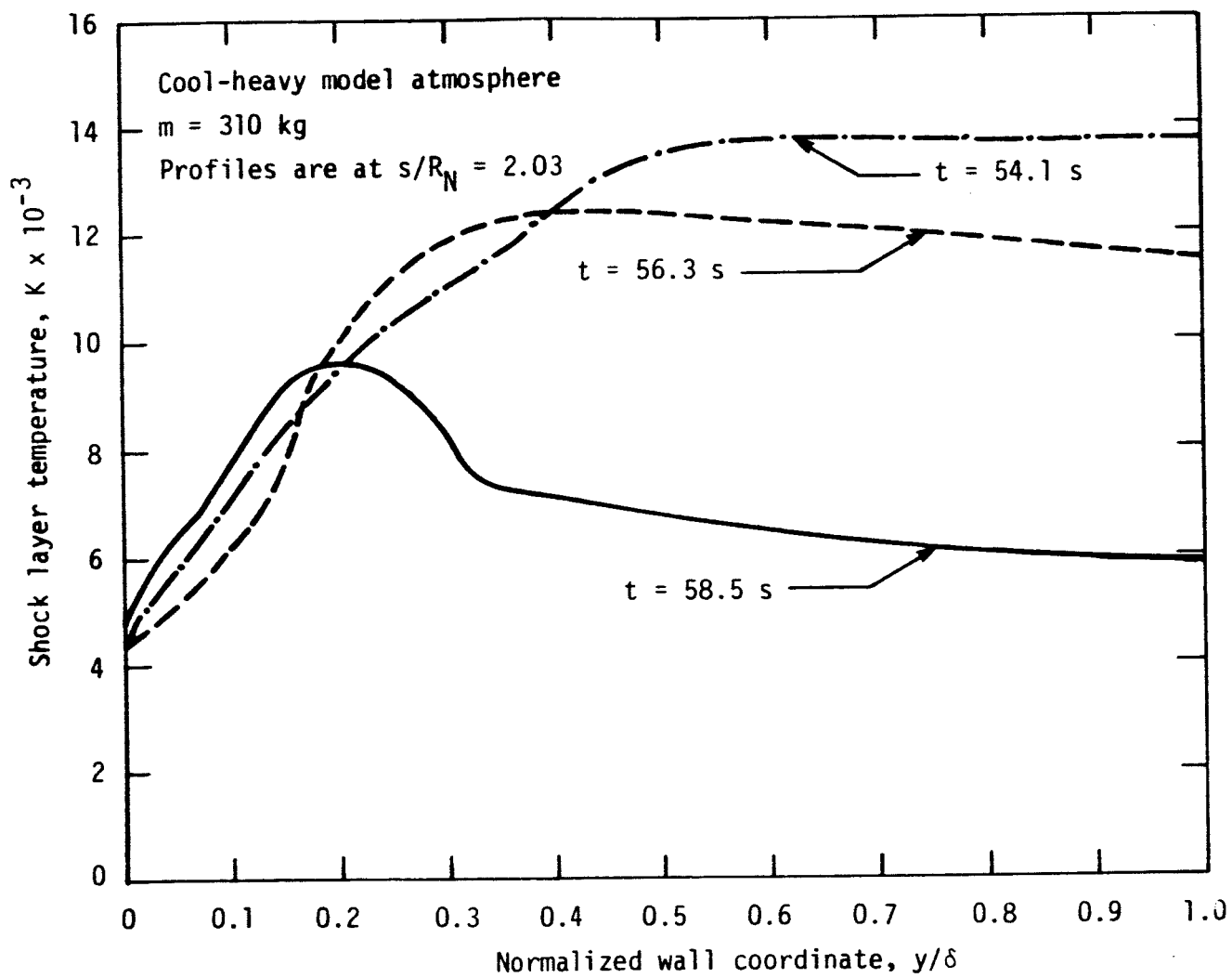


Figure 4-2. Temperature Profiles at $s/R_N = 2.03$ for Entry to Cool-Heavy Model Atmosphere

SECTION 5

CONCLUDING REMARKS

Aerothermal heating and flowfield solutions were presented for the forebody of a 44.25 deg sphere cone entering the atmospheres of Jupiter. A total of 16 cases were considered. The following conclusions were reached as a result of this study:

- a. The heating rates for entry into the cool heavy model atmosphere were about 60 percent higher than those predicted for the entry into the nominal model atmosphere. The total mass lost for entry into the cool heavy model atmosphere was about 146 kg and the mass lost for entry into the nominal model atmosphere was about 101 kg.
- b. The heating rates on the flank region of the probe increased with increase in streamwise distance during early and peak heating times of the heating pulse. At late entry times, the heating rates were found to be leveling off. A decrease in heating rate and hence ablation rate were not found with increase in streamwise distance.
- c. Strong entropy layers or vortical layers were found to be present, particularly during late times in the trajectory.

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APPENDIX A
JUPITER ATMOSPHERE COMPOSITION MODELS
ORTON REVISED

Orton Revised Jupiter Nominal Atmosphere (August 10, 1979)

	ALT(KM)	PRESS(PAR)	TEMP(K)	DENSITY(G/CM3)	CP/CV
1	-282.44	1.0000E+02	679.861	3.9651E-03	1.411196
2	-257.51	7.9433E+01	635.032	3.3687E-03	1.41293
3	-234.20	6.3096E+01	594.230	2.8623E-03	1.41359
4	-212.41	5.0119E+01	555.494	2.4322E-03	1.41406
5	-192.04	3.9811E+01	519.254	2.0668E-03	1.41452
6	-173.00	3.1623E+01	485.354	1.7564E-03	1.41496
7	-155.21	2.5119E+01	453.644	1.4927E-03	1.41540
8	-138.58	1.9953E+01	423.986	1.2680E-03	1.41582
9	-123.03	1.5849E+01	396.247	1.0782E-03	1.41623
10	-108.50	1.2589E+01	370.297	9.1648E-04	1.41698
11	-94.92	1.0000E+01	345.999	7.7911E-04	1.41832
12	-82.22	7.9433E+00	323.232	6.6246E-04	1.42015
13	-70.37	6.3096E+00	301.890	5.6341E-04	1.42238
14	-59.29	5.0119E+00	281.868	4.7932E-04	1.42541
15	-48.94	3.9811E+00	263.062	4.0796E-04	1.42939
16	-39.29	3.1623E+00	245.385	3.4740E-04	1.43407
17	-30.28	2.5119E+00	228.757	2.9600E-04	1.43990
18	-21.87	1.9953E+00	213.090	2.5241E-04	1.44735
19	-14.05	1.5849E+00	198.310	2.1544E-04	1.45621
20	-6.77	1.2589E+00	184.363	1.8409E-04	1.46610
21	0.00	1.0000E+00	171.154	1.5747E-04	1.47764
22	6.28	7.9433E-01	158.754	1.3488E-04	1.49078
23	12.12	6.3096E-01	147.000	1.1568E-04	1.50549
24	17.29	5.0119E-01	134.300	1.0048E-04	1.52435
25	21.59	3.9811E-01	121.600	8.8140E-05	1.54675
26	26.38	3.1623E-01	116.650	7.2982E-05	1.55671
27	30.58	2.5119E-01	111.700	6.0541E-05	1.56094
28	34.67	1.9953E-01	106.900	4.9436E-05	1.56860
29	38.74	1.5849E-01	102.100	3.8754E-05	1.57027
30	42.83	1.2589E-01	97.350	3.0147E-05	1.56559
31	47.01	1.0000E-01	92.600	2.3492E-05	1.56093
32	51.28	7.9433E-02	87.288	1.8233E-05	1.55540
33	55.65	6.3096E-02	81.975	1.4158E-05	1.54991
34	60.12	5.0119E-02	76.663	1.1003E-05	1.54472
35	64.69	3.9811E-02	71.350	8.5502E-06	1.53972
36	69.35	3.1623E-02	66.038	6.6491E-06	1.53491
37	74.12	2.5119E-02	60.725	5.1730E-06	1.53027

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FIG. 3.4

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Orton Revised Jupiter Nominal Atmosphere (Continued)

ALT(KM) PRESS(PAR) TEMP(K) DENSITY(G/CM3) CP/CV

38	78.99	1.9953E-02	133.413	4.0263E-06	1.52579
39	83.95	1.5849E-02	136.100	3.1350E-06	1.52148
40	89.01	1.2589E-02	138.097	2.4542E-06	1.51838
41	94.14	1.0000E-02	140.094	1.9217E-06	1.51537
42	99.34	7.9433E-03	142.091	1.5050E-06	1.51243
43	104.62	6.3096E-03	144.088	1.1789E-06	1.50957
44	109.97	5.0119E-03	146.084	9.2363E-07	1.50679
45	115.40	3.9811E-03	148.081	7.2377E-07	1.50409
46	120.90	3.1623E-03	150.078	5.6726E-07	1.50146
47	126.47	2.5119E-03	152.075	4.4468E-07	1.49890
48	132.12	1.9953E-03	154.072	3.4864E-07	1.49641
49	137.85	1.5849E-03	156.069	2.7339E-07	1.49399
50	143.65	1.2589E-03	158.066	2.1442E-07	1.49163
51	149.52	1.0000E-03	160.063	1.6819E-07	1.48934
52	155.47	7.9433E-04	162.059	1.3196E-07	1.48711
53	161.50	6.3096E-04	164.056	1.0354E-07	1.48495
54	167.60	5.0119E-04	166.053	8.1256E-08	1.48284
55	173.77	3.9811E-04	168.050	6.3777E-08	1.48079
56	180.02	3.1623E-04	170.047	5.0065E-08	1.47881
57	186.35	2.5119E-04	172.044	3.9356E-08	1.47687
58	192.75	1.9953E-04	174.041	3.0864E-08	1.47500
59	199.22	1.5849E-04	176.038	2.4238E-08	1.47318
60	205.77	1.2589E-04	178.034	1.9037E-08	1.47141
61	212.40	1.0000E-04	180.031	1.4954E-08	1.46969
62	219.10	7.9433E-05	182.028	1.1748E-08	1.46803
63	225.88	6.3096E-05	184.025	9.2305E-09	1.46641
64	232.73	5.0119E-05	186.022	7.2533E-09	1.46485
65	239.66	3.9811E-05	188.019	5.7003E-09	1.46333
66	246.66	3.1623E-05	190.016	4.4804E-09	1.46186
67	253.74	2.5119E-05	192.013	3.5219E-09	1.46044
68	260.89	1.9953E-05	194.009	2.7687E-09	1.45906
69	268.12	1.5849E-05	196.006	2.1769E-09	1.45773
70	275.43	1.2589E-05	198.003	1.7117E-09	1.45644
71	282.81	1.0000E-05	200.000	1.3461E-09	1.45520
72	290.23	7.9433E-06	200.000	1.0692E-09	1.45520
73	297.65	6.3096E-06	200.000	8.4932E-10	1.45520
74	305.08	5.0119E-06	200.000	6.7464E-10	1.45520

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			SHEET 2 OF 15	

Orton Revised Jupiter Nominal Atmosphere (Continued)

-----ALT(KM)-----PRESS(PAR)-----TEMP(K)-----DENSITY(G/CM3)-----CP/CV-----

75	312.50	3.9811E-06	200.000	5.3588E-10	1.45520
76	319.93	3.1623E-06	200.000	4.2567E-10	1.45520
77	327.36	2.5119E-06	200.000	3.3812E-10	1.45520
78	334.79	1.9953E-06	200.000	2.6858E-10	1.45520
79	342.22	1.5849E-06	200.000	2.1334E-10	1.45520
80	349.66	1.2589E-06	200.000	1.6946E-10	1.45520
81	357.10	1.0000E-06	200.000	1.3461E-10	1.45520
82	364.94	7.9433E-07	221.667	9.6472E-11	1.44307
83	373.59	6.3096E-07	243.333	6.9807E-11	1.43472
84	383.04	5.0119E-07	265.000	5.0916E-11	1.42896
85	393.31	3.9811E-07	286.667	3.7387E-11	1.42461
86	404.39	3.1623E-07	308.333	2.7611E-11	1.42109
87	416.28	2.5119E-07	330.000	2.1492E-11	1.41859
88	428.98	1.9953E-07	351.667	1.5275E-11	1.41759
89	442.49	1.5849E-07	373.333	1.1429E-11	1.41690
90	456.82	1.2589E-07	395.000	8.5803E-12	1.41629
91	471.96	1.0000E-07	416.667	6.4612E-12	1.41597
92	487.92	7.9433E-08	438.333	4.8786E-12	1.41566
93	504.70	6.3096E-08	460.000	3.6927E-12	1.41536
94	522.30	5.0119E-08	481.667	2.8013E-12	1.41506
95	540.71	3.9811E-08	503.333	2.1293E-12	1.41477
96	559.95	3.1623E-08	525.000	1.6216E-12	1.41449
97	580.01	2.5119E-08	546.667	1.2370E-12	1.41422
98	600.90	1.9953E-08	568.333	9.4514E-13	1.41396
99	622.61	1.5849E-08	590.000	7.2319E-13	1.41370
100	645.15	1.2589E-08	611.667	5.5410E-13	1.41341
101	668.52	1.0000E-08	633.333	4.2508E-13	1.41304
102	692.73	7.9433E-09	655.000	3.2648E-13	1.41260
103	717.76	6.3096E-09	676.667	2.5103E-13	1.41211
104	743.64	5.0119E-09	698.333	1.9321E-13	1.41156
105	770.35	3.9811E-09	720.000	1.4686E-13	1.41095
106	797.90	3.1623E-09	741.667	1.1479E-13	1.41028
107	826.30	2.5119E-09	763.333	8.6591E-14	1.40955
108	855.54	1.9953E-09	785.000	6.8428E-14	1.40876
109	885.62	1.5849E-09	806.667	5.2824E-14	1.40792
110	916.56	1.2589E-09	828.333	4.0915E-14	1.40712
111	948.35	1.0000E-09	850.000	3.1673E-14	1.40607

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		FIG. 3.4		
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Orton Revised Jupiter Cool Heavy Atmosphere (August 10, 1979)

ALT(KM) PRESS(PAR) TEMP(K) DENSITY(G/CM3) CP/CV

1	-258.43	1.0000E+02	657.094	4.3344E-03	1.42426
2	-238.93	7.9433E+01	613.491	3.6912E-03	1.42507
3	-209.72	6.3096E+01	572.743	3.1406E-03	1.42559
4	-190.02	5.0119E+01	534.674	2.6723E-03	1.42606
5	-171.63	3.9811E+01	499.109	2.2739E-03	1.42651
6	-154.47	3.1623E+01	465.887	1.9351E-03	1.42695
7	-138.44	2.5119E+01	434.854	1.6468E-03	1.42738
8	-123.49	1.9953E+01	405.870	1.4015E-03	1.42779
9	-109.53	1.5849E+01	378.797	1.1928E-03	1.42835
10	-96.49	1.2589E+01	353.490	1.0153E-03	1.42891
11	-84.33	1.0000E+01	329.815	8.6438E-04	1.43120
12	-72.98	7.9433E+00	307.657	7.3605E-04	1.43332
13	-62.39	6.3096E+00	286.906	6.2695E-04	1.43606
14	-52.51	5.0119E+00	267.450	5.3423E-04	1.43991
15	-43.30	3.9811E+00	249.192	4.5545E-04	1.44436
16	-34.72	3.1623E+00	232.050	3.8850E-04	1.44979
17	-26.73	2.5119E+00	215.929	3.3164E-04	1.45687
18	-19.29	1.9953E+00	200.750	2.8335E-04	1.46545
19	-12.38	1.5849E+00	186.453	2.4233E-04	1.47497
20	-5.96	1.2589E+00	172.979	2.0748E-04	1.48608
21	0.00	1.0000E+00	160.275	1.7787E-04	1.49874
22	5.52	7.9433E-01	148.294	1.5267E-04	1.51290
23	10.63	6.3096E-01	137.000	1.3116E-04	1.52856
24	15.17	5.0119E-01	124.300	1.1481E-04	1.54719
25	19.28	3.9811E-01	111.600	1.0157E-04	1.57343
26	23.07	3.1623E-01	100.650	8.4426E-05	1.58323
27	26.78	2.5119E-01	101.700	7.0326E-05	1.59313
28	30.22	1.9953E-01	100.900	5.6305E-05	1.59474
29	33.72	1.5849E-01	100.100	4.5082E-05	1.59635
30	37.24	1.2589E-01	102.350	3.5023E-05	1.59183
31	40.84	1.0000E-01	104.600	2.7221E-05	1.58732
32	44.53	7.9433E-02	107.288	2.1081E-05	1.58156
33	48.31	6.3096E-02	109.975	1.6336E-05	1.57663
34	52.19	5.0119E-02	112.663	1.2667E-05	1.57133
35	56.16	3.9811E-02	115.350	9.8270E-06	1.56606
36	60.22	3.1623E-02	118.038	7.6281E-06	1.56082
37	64.38	2.5119E-02	120.725	5.9243E-06	1.55566

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			SHEET 10 OF 15	

Orton Revised Jupiter Cool Heavy Atmosphere (Continued)

ALT(KM) PRESS(PAR) TEMP(K) DENSITY(G/CM3) CP/CV

38	68.63	1.9953E-02	123.413	4.6034E-04	1.55077
39	72.98	1.5849E-02	126.100	3.5787E-04	1.54455
40	77.39	1.2589E-02	127.159	2.8190E-04	1.54474
41	81.84	1.0000E-02	128.219	2.2707E-04	1.54245
42	86.33	7.9433E-03	129.278	1.7485E-04	1.54119
43	90.85	6.3096E-03	130.338	1.3784E-04	1.53905
44	95.41	5.0119E-03	131.397	1.0861E-04	1.53774
45	100.01	3.9811E-03	132.456	8.5578E-05	1.53555
46	104.65	3.1623E-03	133.516	6.7439E-05	1.53388
47	109.33	2.5119E-03	134.575	5.3144E-05	1.53224
48	114.04	1.9953E-03	135.634	4.1864E-05	1.53162
49	118.79	1.5849E-03	136.694	3.3013E-05	1.52993
50	123.58	1.2589E-03	137.753	2.6022E-05	1.52745
51	128.40	1.0000E-03	138.813	2.0512E-05	1.52590
52	133.27	7.9433E-04	139.872	1.6170E-05	1.52437
53	138.17	6.3096E-04	140.931	1.2748E-05	1.52286
54	143.11	5.0119E-04	141.991	1.0050E-05	1.52139
55	148.09	3.9811E-04	143.050	7.9241E-06	1.51991
56	153.10	3.1623E-04	144.109	6.2460E-06	1.51847
57	158.16	2.5119E-04	145.169	4.9268E-06	1.51704
58	163.25	1.9953E-04	146.228	3.8851E-06	1.51564
59	168.37	1.5849E-04	147.288	3.0639E-06	1.51425
60	173.54	1.2589E-04	148.347	2.4153E-06	1.51289
61	178.75	1.0000E-04	149.406	1.9058E-06	1.51154
62	183.99	7.9433E-05	150.466	1.5031E-06	1.51022
63	189.27	6.3096E-05	151.525	1.1856E-06	1.50891
64	194.59	5.0119E-05	152.584	9.3525E-07	1.50762
65	199.94	3.9811E-05	153.644	7.3777E-07	1.50635
66	205.34	3.1623E-05	154.703	5.8202E-07	1.50509
67	210.77	2.5119E-05	155.763	4.5917E-07	1.50386
68	216.24	1.9953E-05	156.822	3.6227E-07	1.50264
69	221.75	1.5849E-05	157.881	2.8593E-07	1.50144
70	227.29	1.2589E-05	158.941	2.2553E-07	1.50026
71	232.88	1.0000E-05	160.000	1.7796E-07	1.49909
72	238.48	7.9433E-06	160.000	1.4135E-07	1.49909
73	244.09	6.3096E-06	160.000	1.1228E-07	1.49909
74	249.69	5.0119E-06	160.000	8.9190E-08	1.49909

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FIG. 3.4

REV. NO.

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OF 15

Orton Revised Jupiter Cool Heavy Atmosphere (Continued)

	ALT(KM)	PRESS(PAR)	TEMP(K)	DENSITY(G/CM3)	CP/CV
75	255.30	3.9811E-06	160.000	7.0846E-10	1.49909
76	260.91	3.1623E-06	160.000	5.6275E-10	1.49909
77	266.52	2.5119E-06	160.000	4.4701E-10	1.49909
78	272.13	1.9953E-06	160.000	3.5507E-10	1.49909
79	277.74	1.5849E-06	160.000	2.8204E-10	1.49909
80	283.35	1.2589E-06	160.000	2.2404E-10	1.49909
81	288.96	1.0000E-06	160.000	1.7756E-10	1.49909
82	294.86	7.9433E-07	176.333	1.2026E-10	1.48315
83	301.34	6.3096E-07	192.667	9.3246E-11	1.47062
84	308.39	5.0119E-07	209.000	6.8279E-11	1.46059
85	316.01	3.9811E-07	225.333	5.0305E-11	1.45254
86	324.21	3.1623E-07	241.667	3.7258E-11	1.44653
87	332.99	2.5119E-07	258.000	2.7721E-11	1.44268
88	342.34	1.9953E-07	274.333	2.0709E-11	1.43839
89	352.27	1.5849E-07	290.667	1.5525E-11	1.43551
90	362.78	1.2589E-07	307.000	1.1676E-11	1.43343
91	373.87	1.0000E-07	323.333	8.8061E-12	1.43181
92	385.53	7.9433E-08	339.667	6.6584E-12	1.43047
93	397.77	6.3096E-08	356.000	5.0465E-12	1.42941
94	410.60	5.0119E-08	372.333	3.8327E-12	1.42863
95	424.00	3.9811E-08	388.667	2.9165E-12	1.42812
96	437.99	3.1623E-08	405.000	2.2232E-12	1.42785
97	452.55	2.5119E-08	421.333	1.6975E-12	1.42762
98	467.71	1.9953E-08	437.667	1.2981E-12	1.42739
99	483.44	1.5849E-08	454.000	9.9399E-13	1.42717
100	499.76	1.2589E-08	470.333	7.6213E-13	1.42695
101	516.67	1.0000E-08	486.667	5.8507E-13	1.42673
102	534.16	7.9433E-09	503.000	4.4964E-13	1.42652
103	552.24	6.3096E-09	519.333	3.4553E-13	1.42631
104	570.91	5.0119E-09	535.667	2.6640E-13	1.42610
105	590.17	3.9811E-09	552.000	2.0525E-13	1.42590
106	610.02	3.1623E-09	568.333	1.5843E-13	1.42571
107	630.46	2.5119E-09	584.667	1.2233E-13	1.42552
108	651.50	1.9953E-09	601.000	9.4528E-14	1.42533
109	673.13	1.5849E-09	617.333	7.3100E-14	1.42508
110	695.35	1.2589E-09	633.667	5.6569E-14	1.42480
111	718.17	1.0000E-09	650.000	4.3805E-14	1.42449

REPRODUCED FROM

TITLE

JUPITER ATMOSPHERE THERMODYNAMIC
STATE PROPERTIES MODELS

NASA
AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA

DOC. NO. JP-590.04

FIG. 3.4

REV. NO.

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OF 15

APPENDIX B

TABLE 1

Table a. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 43.0 sec

Orton nominal model atmosphere
Nose radius $R_N = 0.352$ m
44.250 sphere cone shape

Freestream conditions
 $u_\infty = 46.58$ km/s
 $\rho_\infty = 8.059 \times 10^{-5}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\dot{m}/\rho_\infty v_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance η_5/R_N	Temperature T_S , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_S	Enthalpy H_w , MJ/kg	Temperature T_w , K
0.000	82.7	0.15	0.835	0.0814	15,700	1.611*5	9.963-4	90.0	21.90	3,800
0.0986	84.7	0.60	0.861	0.0892	15,600	1.591*5	9.963-4	84.78	21.90	3,800
0.1644	83.9	0.96	0.853	0.0909	15,600	1.571*5	9.931-4	81.30	21.92	3,790
0.2057	82.6	1.20	0.843	0.0927	15,500	1.550*5	9.915-4	79.12	21.92	3,790
0.2474	80.9	1.44	0.828	0.0944	15,400	1.520*5	9.883-4	76.94	21.92	3,790
0.2894	78.8	1.68	0.807	0.0961	15,300	1.489*5	9.835-4	74.76	21.92	3,790
0.3318	76.3	1.93	0.780	0.0979	15,100	1.459*5	9.803-4	72.56	21.92	3,780
0.3747	73.3	2.18	0.750	0.0996	15,000	1.419*5	9.739-4	70.36	21.94	3,780
0.4182	70.0	2.45	0.714	0.1013	14,800	1.378*5	9.675-4	68.15	21.94	3,770
0.4624	66.4	2.75	0.676	0.1039	14,700	1.337*5	9.611-4	65.92	21.94	3,770
0.5074	62.7	3.03	0.637	0.1065	14,500	1.287*5	9.515-4	63.67	21.97	3,760
0.5532	58.5	3.29	0.591	0.1091	14,300	1.236*5	9.419-4	61.40	21.97	3,760
0.6000	53.9	3.54	0.542	0.1117	14,000	1.175*5	9.307-4	59.10	21.99	3,750
0.6480	49.3	3.80	0.491	0.1152	13,800	1.115*5	9.179-4	56.77	22.01	3,740
0.6975	42.6	4.15	0.420	0.1204	13,400	1.034*5	8.970-4	53.53	22.04	3,720
0.7483	37.5	4.51	0.365	0.1247	13,100	9.616*4	8.794-4	51.08	22.08	3,710
0.8009	32.3	4.87	0.311	0.1299	12,800	9.119*4	8.666-4	49.34	22.13	3,700
0.9255	36.2	5.25	0.359	0.1394	12,800	9.119*4	8.666-4	49.34	22.13	3,700
1.0430	38.8	4.98	0.386	0.1524	12,800	9.119*4	8.666-4	49.34	22.11	3,700
1.1018	39.4	4.90	0.391	0.1593	12,800	9.119*4	8.666-4	49.34	22.11	3,700
1.1606	39.8	4.82	0.395	0.1654	12,800	9.119*4	8.666-4	49.34	22.11	3,700
1.2781	41.5	4.57	0.412	0.1784	12,800	9.119*4	8.666-4	49.34	22.11	3,710
1.3956	42.9	4.36	0.426	0.1905	12,800	9.119*4	8.666-4	49.34	22.08	3,710
1.5132	44.2	4.17	0.438	0.2035	12,800	9.119*4	8.666-4	49.34	22.08	3,710
1.6307	45.6	3.98	0.452	0.2165	12,800	9.119*4	8.666-4	49.34	22.08	3,710
1.7482	47.1	3.80	0.467	0.2286	12,800	9.119*4	8.666-4	49.34	22.08	3,710
1.8658	48.5	3.63	0.482	0.2416	12,800	9.119*4	8.666-4	49.34	22.08	3,710
1.9833	49.9	3.47	0.497	0.2546	12,800	9.119*4	8.666-4	49.34	22.08	3,710
2.1009	51.3	3.33	0.511	0.2676	12,800	9.119*4	8.666-4	49.34	22.08	3,710
2.2186	52.8	3.18	0.526	0.2814	12,800	9.119*4	8.666-4	49.34	22.08	3,710

Table b. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 47.0 sec

Orton nominal model atmosphere
Nose radius $R_N = 0.352$ m
44.25° sphere cone shape

Freestream conditions
 $u_\infty = 44.47$ km/s
 $\rho_\infty = 1.869 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance S_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $m/\rho_\infty V_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance n_S/R_N	Temperature T_S , K	Pressure P , N/m^2	Density ρ , kg/m^3	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K
0.000	165.7	0.23	0.813	0.0872	16,100	3.374+5	2.162-3	90.0	21.73	3,900
0.0981	173.6	0.69	0.858	0.0935	16,000	3.344+5	2.162-3	84.83	21.73	3,900
0.1636	173.6	1.04	0.860	0.0953	15,900	3.303+5	2.146-3	81.38	21.73	3,900
0.2048	172.5	1.26	0.855	0.0961	15,800	3.253+5	2.146-3	79.22	21.73	3,900
0.2464	170.2	1.45	0.847	0.0979	15,700	3.202+5	2.130-3	77.06	21.73	3,890
0.2882	168.0	1.66	0.833	0.0996	15,600	3.141+5	2.130-3	74.89	21.73	3,890
0.3305	164.6	1.85	0.817	0.1013	15,500	3.070+5	2.114-3	72.72	21.76	3,890
0.3732	158.9	2.08	0.791	0.1030	15,100	2.989+5	2.114-3	70.53	21.76	3,880
0.4166	153.2	2.30	0.762	0.1056	15,200	2.908+5	2.098-3	68.34	21.76	3,880
0.4606	147.5	2.58	0.729	0.1074	15,000	2.817+5	2.082-3	66.12	21.76	3,870
0.5053	140.7	2.88	0.696	0.1100	14,800	2.705+5	2.050-3	63.89	21.78	3,870
0.5509	131.7	3.19	0.653	0.1126	14,600	2.594+5	2.034-3	61.62	21.78	3,860
0.5975	122.6	3.52	0.606	0.1160	14,300	2.482+5	2.002-3	59.33	21.78	3,860
0.6452	113.2	3.88	0.556	0.1195	14,000	2.351+5	1.986-3	57.02	21.80	3,850
0.6944	98.5	4.45	0.482	0.1256	13,700	2.178+5	1.938-3	53.78	21.83	3,830
0.7448	86.71	4.87	0.422	0.1299	13,300	2.037+5	1.906-3	51.34	21.83	3,820
0.7970	75.02	5.27	0.363	0.1351	13,000	1.925+5	1.874-3	49.51	21.85	3,810
0.9215	85.23	5.86	0.420	0.1463	13,000	1.925+5	1.874-3	49.51	21.85	3,810
1.0390	90.11	5.61	0.444	0.1611	13,000	1.925+5	1.874-3	49.51	21.85	3,810
1.0976	90.91	5.53	0.448	0.1680	13,000	1.925+5	1.874-3	49.51	21.85	3,810
1.1564	91.25	5.42	0.449	0.1758	13,000	1.925+5	1.874-3	49.51	21.85	3,810
1.2738	93.29	5.14	0.458	0.1896	13,000	1.925+5	1.874-3	49.51	21.85	3,810
1.3911	94.76	4.86	0.465	0.2035	13,000	1.925+5	1.874-3	49.51	21.85	3,820
1.5085	96.13	4.57	0.470	0.2173	13,000	1.925+5	1.874-3	49.51	21.85	3,820
1.6259	97.71	4.32	0.478	0.2312	13,000	1.925+5	1.874-3	49.51	21.85	3,820
1.7431	99.76	4.10	0.486	0.2442	13,000	1.925+5	1.874-3	49.51	21.85	3,820
1.8605	101.8	3.89	0.497	0.2580	13,000	1.925+5	1.874-3	49.51	21.85	3,820
1.9778	104.2	3.72	0.509	0.2719	13,000	1.925+5	1.874-3	49.51	21.85	3,820
2.0952	106.3	3.55	0.520	0.2858	13,000	1.925+5	1.874-3	49.51	21.85	3,820
2.2126	108.6	3.40	0.531	0.2996	13,000	1.925+5	1.874-3	49.51	21.85	3,820

Table c. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 49.2 sec

Orton nominal model atmosphere
Nose radius $R_N = 0.352$ m
44.250 sphere cone shape

Freestream conditions
 $u_\infty = 42.3$ km/s
 $\rho_\infty = 3.046 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\dot{m}/\rho_\infty v_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance η_S/R_N	Temperature T_S , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K
0.000	216.8	0.29	0.703	0.0900	16,000	4.955+5	3.348-3	90.00	21.66	3,960
0.0979	228.1	0.87	0.740	0.0953	15,900	4.914+5	3.348-3	84.86	21.66	3,960
0.1633	229.3	1.29	0.744	0.0961	15,800	4.843+5	3.332-3	81.44	21.66	3,960
0.2045	228.1	1.55	0.744	0.0979	15,800	4.783+5	3.316-3	79.30	21.66	3,950
0.2460	225.8	1.79	0.739	0.0996	15,700	4.701+5	3.316-3	77.15	21.66	3,950
0.2878	222.4	2.03	0.728	0.1004	15,600	4.610+5	3.300-3	75.00	21.69	3,950
0.3300	217.9	2.27	0.714	0.1022	15,400	4.509+5	3.284-3	72.84	21.69	3,940
0.3727	213.4	2.52	0.698	0.1039	15,300	4.398+5	3.252-3	70.67	21.69	3,940
0.4160	206.6	2.79	0.675	0.1065	15,100	4.276+5	3.236-3	68.48	21.69	3,940
0.4599	198.6	3.12	0.648	0.1082	14,900	4.134+5	3.204-3	66.28	21.69	3,930
0.5046	190.7	3.48	0.621	0.1108	14,700	3.982+5	3.172-3	64.06	21.69	3,930
0.5501	179.3	3.87	0.586	0.1134	14,500	3.820+5	3.140-3	61.80	21.71	3,920
0.5966	168.0	4.27	0.547	0.1169	14,200	3.648+5	3.108-3	59.52	21.71	3,910
0.6442	155.5	4.72	0.506	0.1204	13,900	3.465+5	3.060-3	57.21	21.71	3,900
0.6931	135.1	5.45	0.437	0.1256	13,500	3.202+5	2.995-3	53.99	21.73	3,890
0.7435	118.0	6.01	0.382	0.1308	13,100	2.999+5	2.947-3	51.55	21.73	3,880
0.7954	100.9	6.61	0.326	0.1359	12,700	2.837+5	2.899-3	49.66	21.76	3,870
0.9195	115.8	7.42	0.379	0.1472	12,700	2.837+5	2.899-3	49.66	21.76	3,870
1.0366	121.4	7.06	0.396	0.1611	12,700	2.837+5	2.899-3	49.66	21.76	3,870
1.0953	121.4	6.95	0.398	0.1689	12,700	2.837+5	2.899-3	49.66	21.76	3,870
1.1539	121.4	6.81	0.398	0.1758	12,700	2.837+5	2.899-3	49.66	21.76	3,870
1.2710	122.6	6.49	0.400	0.1896	12,700	2.837+5	2.899-3	49.66	21.76	3,870
1.3880	123.7	6.21	0.402	0.2026	12,700	2.837+5	2.899-3	49.66	21.76	3,870
1.5050	123.7	5.94	0.403	0.2156	12,700	2.837+5	2.899-3	49.66	21.76	3,870
1.6221	124.8	5.70	0.406	0.2295	12,700	2.837+5	2.899-3	49.66	21.76	3,870
1.7391	127.1	5.47	0.411	0.2425	12,700	2.837+5	2.899-3	49.66	21.76	3,870
1.8561	129.4	5.24	0.419	0.2554	12,700	2.837+5	2.899-3	49.66	21.76	3,870
1.9731	131.7	5.05	0.427	0.2684	12,700	2.837+5	2.899-3	49.66	21.76	3,870
2.0902	133.9	4.86	0.435	0.2823	12,700	2.837+5	2.899-3	49.66	21.76	3,870
2.2073	137.3	4.68	0.443	0.2953	12,700	2.837+5	2.899-3	49.66	21.76	3,870

Table d. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 50.3 sec

Orton nominal model atmosphere
Nose radius $R_N = 0.352$ m
44.25° sphere cone shape

Freestream conditions
 $u_\infty = 40.87$ km/s
 $\rho_\infty = 3.861 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\dot{m}/\rho_\infty V_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance η_S/R_N	Temperature T_S , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K
0.000	237.2	0.32	0.630	0.0913	15,800	5.846+5	4.117-3	90.00	21.64	3,980
0.0978	247.4	0.96	0.660	0.0953	15,800	5.796+5	4.117-3	84.89	21.64	3,980
0.1633	249.7	1.45	0.663	0.0970	15,700	5.715+5	4.101-3	81.48	21.64	3,980
0.2044	248.5	1.76	0.663	0.0979	15,600	5.644+5	4.085-3	79.35	21.64	3,980
0.2459	246.3	2.03	0.658	0.0996	15,500	5.553+5	4.069-3	77.21	21.64	3,980
0.2877	242.9	2.29	0.651	0.1013	15,400	5.441+5	4.053-3	75.07	21.64	3,970
0.3299	237.2	2.56	0.638	0.1022	15,200	5.330+5	4.021-3	72.92	21.66	3,970
0.3726	231.5	2.82	0.622	0.1039	15,100	5.198+5	4.005-3	70.75	21.66	3,970
0.4159	225.8	3.18	0.605	0.1065	14,900	5.046+5	3.973-3	68.58	21.66	3,960
0.4598	216.9	3.55	0.582	0.1082	14,700	4.884+5	3.941-3	66.38	21.66	3,960
0.5044	206.6	4.02	0.554	0.1108	14,500	4.712+5	3.909-3	64.16	21.66	3,950
0.5498	196.3	4.43	0.526	0.1134	14,300	4.519+5	3.860-3	61.92	21.66	3,940
0.5963	187.7	4.91	0.490	0.1169	14,000	4.316+5	3.812-3	59.64	21.69	3,940
0.6438	168.0	5.52	0.452	0.1204	13,700	4.104+5	3.764-3	57.34	21.69	3,930
0.6927	145.3	6.32	0.387	0.1256	13,300	3.790+5	3.684-3	54.12	21.71	3,910
0.7429	126.0	7.01	0.337	0.1299	12,900	3.546+5	3.620-3	51.68	21.71	3,900
0.7948	107.0	7.79	0.286	0.1351	12,500	3.354+5	3.588-3	49.75	21.73	3,890
0.9187	122.6	8.81	0.333	0.1463	12,500	3.354+5	3.588-3	49.75	21.73	3,890
1.0356	128.2	8.40	0.346	0.1602	12,500	3.354+5	3.588-3	49.75	21.73	3,890
1.0941	128.2	8.28	0.347	0.1671	12,500	3.354+5	3.588-3	49.75	21.73	3,890
1.1525	128.2	8.16	0.346	0.1732	12,500	3.354+5	3.588-3	49.75	21.73	3,890
1.2695	128.2	7.85	0.346	0.1870	12,500	3.354+5	3.588-3	49.75	21.73	3,890
1.3862	128.2	7.57	0.346	0.1992	12,500	3.354+5	3.588-3	49.75	21.73	3,890
1.5031	128.2	7.31	0.345	0.2121	12,500	3.354+5	3.588-3	49.75	21.73	3,890
1.6199	129.4	7.07	0.346	0.2251	12,500	3.354+5	3.588-3	49.75	21.73	3,890
1.7367	130.5	6.84	0.350	0.2373	12,500	3.354+5	3.588-3	49.75	21.73	3,890
1.8535	132.8	6.62	0.355	0.2502	12,500	3.354+5	3.588-3	49.75	21.73	3,890
1.9703	135.1	6.40	0.362	0.2624	12,500	3.354+5	3.588-3	49.75	21.73	3,890
2.0872	138.5	6.21	0.369	0.2754	12,500	3.354+5	3.588-3	49.75	21.73	3,890
2.2040	140.7	6.00	0.376	0.2883	12,500	3.354+5	3.588-3	49.75	21.73	3,890

Table e. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 51.5 sec

Orton nominal model atmosphere
Nose radius $R_N = 0.352$ m
44.250 sphere cone shape

Freestream conditions
 $u_\infty = 39.04$ km/s
 $\rho_\infty = 4.966 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\text{m}/\rho_\infty v_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance η_S/R_N	Temperature T_S , K	Pressure P , N/m^2	Density ρ , kg/m^3	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K
0.000	248.5	0.35	0.538	0.0924	15,500	6.829*5	5.110-3	90.00	21.62	4,010
0.0978	261.0	1.15	0.567	0.0961	15,400	6.779*5	5.094-3	84.92	21.62	4,000
0.1632	263.3	1.73	0.571	0.0979	15,400	6.677*5	5.078-3	81.53	21.62	4,000
0.2043	261.0	2.05	0.570	0.0987	15,300	6.596*5	5.062-3	79.41	21.64	4,000
0.2458	258.8	2.38	0.566	0.0996	15,200	6.495*5	5.046-3	77.28	21.64	4,000
0.2876	255.4	2.71	0.560	0.1013	15,100	6.373*5	5.014-3	75.15	21.64	4,000
0.3298	250.8	3.06	0.549	0.1030	14,900	6.231*5	4.982-3	73.01	21.64	3,990
0.3724	244.0	3.45	0.536	0.1048	14,800	6.080*5	4.950-3	70.86	21.64	3,990
0.4156	237.2	3.90	0.521	0.1065	14,600	5.907*5	4.918-3	68.69	21.64	3,980
0.4595	227.0	4.39	0.499	0.1082	14,400	5.715*5	4.886-3	66.50	21.64	3,980
0.5041	215.6	4.90	0.474	0.1108	14,200	5.512*5	4.838-3	64.29	21.64	3,970
0.5495	203.2	5.48	0.447	0.1134	13,900	5.289*5	4.790-3	62.06	21.64	3,970
0.5958	188.4	6.24	0.414	0.1160	13,600	5.056*5	4.725-3	59.79	21.66	3,960
0.6433	170.2	6.92	0.375	0.1195	13,300	4.813*5	4.661-3	57.49	21.66	3,950
0.6922	144.1	7.94	0.317	0.1247	12,800	4.448*5	4.581-3	54.28	21.69	3,930
0.7423	123.7	8.93	0.273	0.1290	12,300	4.164*5	4.533-3	51.85	21.69	3,920
0.7940	103.7	10.06	0.231	0.1334	11,900	3.931*5	4.485-3	49.86	21.73	3,900
0.9176	118.0	11.24	0.267	0.1446	11,900	3.931*5	4.485-3	49.86	21.73	3,910
1.0343	123.7	10.92	0.277	0.1576	11,900	3.931*5	4.485-3	49.86	21.73	3,910
1.0927	123.7	10.85	0.277	0.1645	11,900	3.931*5	4.485-3	49.86	21.73	3,910
1.1510	122.6	10.77	0.275	0.1706	11,900	3.931*5	4.485-3	49.86	21.73	3,910
1.2675	122.6	10.52	0.274	0.1827	11,900	3.931*5	4.485-3	49.86	21.73	3,910
1.3840	121.4	10.29	0.271	0.1940	11,900	3.931*5	4.485-3	49.86	21.73	3,910
1.5006	120.3	10.09	0.269	0.2061	11,900	3.931*5	4.485-3	49.86	21.73	3,910
1.6171	120.3	9.87	0.268	0.2173	11,900	3.931*5	4.485-3	49.86	21.73	3,910
1.7336	121.4	9.66	0.270	0.2295	11,900	3.931*5	4.485-3	49.86	21.73	3,910
1.8501	123.7	9.44	0.274	0.2407	11,900	3.931*5	4.485-3	49.86	21.73	3,910
1.9667	126.0	9.22	0.279	0.2528	11,900	3.931*5	4.485-3	49.86	21.73	3,910
2.0831	128.2	8.99	0.284	0.2641	11,900	3.931*5	4.485-3	49.86	21.73	3,910
2.1997	130.5	8.75	0.289	0.2762	11,900	3.931*5	4.485-3	49.86	21.73	3,910

Table f. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 54.1 sec

Orton nominal model atmosphere

Nose radius $R_N = 0.352$ m

44.250 sphere cone shape

Freestream conditions

 $u_\infty = 34.12$ km/s $\rho_\infty = 8.262 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\dot{m}/\rho_\infty u_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance η_S/R_N	Temperature T_S , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K
0.000	210.0	0.40	0.309	0.1204	14,200	8.582+5	7.705-3	90.00	21.59	4,040
0.0978	228.1	0.99	0.338	0.1230	14,100	8.521+5	7.689-3	85.00	21.59	4,040
0.1632	229.3	1.60	0.340	0.1385	14,100	8.400+5	7.657-3	81.67	21.59	4,040
0.2044	227.0	2.03	0.338	0.1437	14,000	8.299+5	7.641-3	79.58	21.59	4,040
0.2459	223.6	2.49	0.332	0.1481	13,900	8.167+5	7.609-3	77.49	21.59	4,030
0.2877	216.8	2.93	0.323	0.1524	13,700	8.025+5	7.577-3	75.39	21.62	4,030
0.3298	208.8	3.40	0.312	0.1611	13,600	7.853+5	7.545-3	73.28	21.62	4,030
0.3725	198.6	3.94	0.296	0.1697	13,400	7.670+5	7.513-3	71.15	21.62	4,020
0.4157	187.3	4.56	0.279	0.1775	13,200	7.458+5	7.465-3	69.01	21.62	4,020
0.4595	173.6	5.32	0.260	0.1862	13,000	7.224+5	7.417-3	66.85	21.62	4,010
0.5041	158.9	6.20	0.238	0.1948	12,700	6.971+5	7.368-3	64.67	22.08	4,000
0.5494	141.9	7.31	0.213	0.2044	12,400	6.708+5	7.336-3	62.45	22.45	3,990
0.5957	123.7	8.80	0.187	0.2130	12,000	6.424+5	7.304-3	60.20	22.62	3,980
0.6430	105.2	10.62	0.160	0.2225	11,600	6.120+5	7.288-3	57.92	22.64	3,960
0.6917	80.6	13.73	0.126	0.2329	11,300	5.684+5	7.320-3	54.73	22.69	3,930
0.7416	62.65	16.12	0.102	0.0941	10,800	5.350+5	7.433-3	52.31	22.71	3,900
0.7933	46.76	18.27	0.0802	0.0970	10,200	5.056+5	7.657-3	50.18	22.71	3,860
0.9745	52.09	17.48	0.0867	0.0979	10,200	5.056+5	7.657-3	50.18	22.73	3,840
1.0324	51.30	17.02	0.0847	0.0987	10,200	5.056+5	7.657-3	50.18	22.73	3,830
1.0902	50.28	17.14	0.0833	0.1004	10,200	5.056+5	7.657-3	50.18	22.73	3,830
1.1481	49.14	17.59	0.0822	0.1013	10,200	5.056+5	7.657-3	50.18	22.76	3,830
1.2638	47.55	19.29	0.0825	0.1022	10,200	5.056+5	7.657-3	50.18	22.76	3,830
1.3795	45.85	20.54	0.0817	0.1039	10,200	5.056+5	7.657-3	50.18	22.76	3,830
1.4952	44.03	21.34	0.0802	0.1056	10,200	5.056+5	7.657-3	50.18	22.76	3,830
1.6109	42.67	22.02	0.0791	0.1065	10,200	5.056+5	7.657-3	50.18	22.76	3,830
1.7266	41.88	22.58	0.0788	0.1091	10,200	5.056+5	7.657-3	50.18	22.76	3,830
1.8424	41.65	23.04	0.0793	0.1108	10,200	5.056+5	7.657-3	50.18	22.76	3,830
1.9581	41.99	23.49	0.0804	0.1126	10,200	5.056+5	7.657-3	50.18	22.76	3,830
2.0739	42.67	23.83	0.0820	0.1152	10,200	5.056+5	7.657-3	50.18	22.76	3,830
2.1897	43.81	24.17	0.0843	0.1186	10,200	5.056+5	7.657-3	50.18	22.76	3,840

Table g. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 56.7 sec

Orton nominal model atmosphere
Nose radius $R_N = 0.352$ m
44.250 sphere cone shape

Freestream conditions
 $u_\infty = 28.37$ km/s
 $\rho_\infty = 1.290 \times 10^{-3}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\dot{m}/\rho_\infty v_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance η_S/R_N	Temperature T_S , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K
0.000	65.14	1.52	0.0626	0.0917	11,400	9.190+5	1.121-2	90.00	21.59	4,050
0.0960	65.71	9.08	0.0727	0.0944	11,300	9.119+5	1.123-2	85.07	21.73	4,010
0.1603	60.26	14.30	0.0724	0.0953	11,200	9.008+5	1.124-2	81.78	21.97	3,980
0.2008	55.50	17.48	0.0703	0.0953	11,000	8.896+5	1.128-2	79.72	22.13	3,960
0.2415	50.05	20.54	0.0674	0.0961	10,900	8.775+5	1.131-2	77.65	22.31	3,940
0.2825	44.03	23.72	0.0639	0.0961	10,700	8.633+5	1.136-2	75.58	22.52	3,910
0.3239	37.91	26.67	0.0601	0.0970	10,400	8.471+5	1.144-2	73.50	22.76	3,880
0.3658	31.66	29.62	0.0561	0.0970	10,100	8.278+5	1.153-2	71.40	22.99	3,850
0.4082	25.88	32.23	0.0524	0.0979	9,770	8.076+5	1.169-2	69.28	23.20	3,820
0.4511	20.43	34.73	0.0491	0.0979	9,350	7.863+5	1.192-2	67.14	23.48	3,790
0.4948	15.55	35.75	0.0449	0.0979	8,860	7.620+5	1.222-2	64.99	23.71	3,760
0.5393	11.80	37.00	0.0421	0.0987	8,280	7.376+5	1.267-2	62.78	23.71	3,730
0.5846	8.70	38.47	0.0403	0.0987	7,640	7.103+5	1.326-2	60.55	23.94	3,700
0.6310	6.28	39.72	0.0391	0.0987	6,960	6.819+5	1.402-2	58.28	24.17	3,680
0.6786	4.40	40.63	0.0381	0.0979	6,310	6.515+5	1.487-2	55.98	24.17	3,660
0.7276	3.02	40.86	0.0369	0.0979	5,770	6.181+5	1.567-2	53.63	24.41	3,640
0.7782	2.05	40.63	0.0357	0.0987	5,360	5.816+5	1.618-2	51.26	24.41	3,630
0.8305	1.40	40.18	0.0345	0.0996	5,050	5.431+5	1.666-2	48.85	24.64	3,610
0.8574	1.15	39.72	0.0337	0.1004	4,970	5.299+5	1.666-2	48.08	24.64	3,610
0.9168	1.19	39.95	0.0341	0.1048	4,970	5.299+5	1.666-2	48.08	24.64	3,610
0.9460	1.18	40.18	0.0342	0.1056	4,970	5.299+5	1.666-2	48.08	24.64	3,610
1.0042	1.17	40.74	0.0348	0.1082	4,970	5.299+5	1.666-2	48.08	24.64	3,610
1.1207	1.18	41.31	0.0355	0.1134	4,970	5.299+5	1.666-2	48.08	24.41	3,620
1.2372	1.15	41.42	0.0355	0.1186	4,970	5.299+5	1.666-2	48.08	24.41	3,630
1.3536	1.11	41.42	0.0355	0.1230	4,970	5.299+5	1.666-2	48.08	24.41	3,630
1.4701	1.07	41.42	0.0354	0.1273	4,970	5.299+5	1.666-2	48.08	24.41	3,630
1.5865	1.03	41.54	0.0355	0.1325	4,970	5.299+5	1.666-2	48.08	24.41	3,640
1.7030	1.00	41.76	0.0357	0.1377	4,970	5.299+5	1.666-2	48.08	24.41	3,640
1.8198	0.97	42.10	0.0361	0.1437	4,970	5.299+5	1.666-2	48.08	24.41	3,640
1.9360	0.95	42.79	0.0368	0.1489	4,970	5.299+5	1.666-2	48.08	24.41	3,640
2.0526	0.94	43.58	0.0376	0.1559	4,970	5.299+5	1.666-2	48.08	24.41	3,640
2.1691	0.94	44.15	0.0382	0.1619	4,970	5.299+5	1.666-2	48.08	24.41	3,650
2.2857	0.95	44.71	0.0388	0.1689	4,970	5.299+5	1.666-2	48.08	24.41	3,650

APPENDIX C

TABLE 2

Table a. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 45.75 sec
m = 290 kgOrton nominal model atmosphere
Nose radius $R_N = 0.352$ m
44.250 sphere cone shapeFreestream conditions
 $u_\infty = 44.22$ km/s
 $\rho_\infty = 2.03 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\dot{m}/\rho_\infty v_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance r_s/R_N	Temperature T_s , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_s	Enthalpy H_w , MJ/kg	Temperature T_w , K
0.000	174.8	0.24	0.799	0.0856	16,100	3.617+5	2.323-3	90.00	21.71	3,910
0.098	182.7	0.74	0.841	0.0909	16,000	3.587+5	2.323-3	84.71	21.71	3,910
0.164	183.9	1.10	0.844	0.0935	15,900	3.536+5	2.323-3	81.18	21.71	3,910
0.247	181.6	1.54	0.835	0.0961	15,700	3.425+5	2.307-3	76.77	21.73	3,900
0.289	179.3	1.76	0.828	0.0970	15,600	3.364+5	2.291-3	74.55	21.73	3,900
0.331	174.8	1.97	0.806	0.0996	15,500	3.283+5	2.275-3	72.33	21.73	3,900
0.374	169.1	2.20	0.782	0.1013	15,300	3.192+5	2.259-3	70.09	21.73	3,890
0.417	162.3	2.45	0.750	0.1030	15,200	3.101+5	2.243-3	67.84	21.73	3,890
0.461	154.4	2.74	0.714	0.1056	15,000	2.989+5	2.227-3	65.57	21.76	3,880
0.506	146.4	3.08	0.677	0.1082	14,800	2.878+5	2.211-3	63.28	21.76	3,880
0.552	138.5	3.42	0.635	0.1108	14,500	2.746+5	2.179-3	60.96	21.76	3,870
0.599	128.2	3.76	0.587	0.1143	14,200	2.614+5	2.162-3	58.61	21.78	3,860
0.646	116.9	4.18	0.535	0.1186	14,000	2.482+5	2.130-3	56.23	21.80	3,850
0.695	105.6	4.64	0.483	0.1230	13,600	2.330+5	2.082-3	53.81	21.80	3,830
0.746	93.1	5.06	0.423	0.1273	13,300	2.178+5	2.050-3	51.37	21.80	3,820
0.798	80.5	5.47	0.364	0.1334	13,000	2.067+5	2.018-3	49.53	21.83	3,820
0.855	68.3	5.91	0.306	0.1394	13,000	2.067+5	2.018-3	49.53	21.83	3,820
0.881	61.9	6.19	0.276	0.1437	13,000	2.067+5	2.018-3	4.953	21.83	3,820
0.923	91.7	6.06	0.421	0.1456	13,000	2.067+5	2.018-3	49.53	21.83	3,820
1.040	97.3	5.78	0.447	0.1602	13,000	2.067+5	2.018-3	49.53	21.83	3,820
1.099	98.2	5.69	0.451	0.1671	13,000	2.067+5	2.018-3	49.53	21.83	3,830
1.158	98.5	5.56	0.452	0.1749	13,000	2.067+5	2.018-3	49.53	21.83	3,830
1.275	100.4	5.25	0.460	0.1888	13,000	2.067+5	2.018-3	49.53	21.83	3,830
1.392	101.8	4.95	0.465	0.2026	13,000	2.067+5	2.018-3	49.53	21.83	3,830
1.500	103.1	4.66	0.470	0.2173	13,000	2.067+5	2.018-3	49.53	21.83	3,830
1.627	104.5	4.40	0.476	0.2312	13,000	2.067+5	2.018-3	49.53	21.83	3,830
1.744	106.5	4.19	0.484	0.2442	13,000	2.067+5	2.018-3	49.53	21.83	3,830
1.862	108.6	3.98	0.494	0.2580	13,000	2.067+5	2.018-3	49.53	21.83	3,830
1.979	110.9	3.80	0.505	0.2719	13,000	2.067+5	2.018-3	49.53	21.83	3,830
2.096	113.2	3.63	0.515	0.2858	13,000	2.067+5	2.018-3	49.53	21.83	3,830
2.214	115.8	3.48	0.525	0.2996	13,000	2.067+5	2.018-3	49.53	21.83	3,830

Table b. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 49.5 sec

m = 290 kg

Orton nominal model atmosphere

Nose radius $R_N = 0.352$ m

44.250 sphere cone shape

Freestream conditions

 $u_\infty = 39.53$ km/s $\rho_\infty = 4.75 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\dot{m}/\rho_\infty v_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance η_S/R_N	Temperature T_S , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_S	Enthalpy H_w , MJ/kg	Temperature T_w , K
0.000	249.7	0.35	0.562	0.0900	15,600	6.687+5	4.918-3	90.00	21.62	4,000
0.098	262.2	1.15	0.591	0.0935	15,600	6.637+5	4.902-3	84.79	21.64	4,000
0.164	264.4	1.73	0.595	0.0953	15,500	6.535+5	4.886-3	81.32	21.64	4,000
0.246	259.9	2.38	0.587	0.0979	15,300	6.343+5	4.854-3	76.97	21.64	4,000
0.288	256.5	2.71	0.581	0.0996	15,200	6.221+5	4.822-3	74.78	21.64	3,990
0.331	250.8	3.06	0.569	0.1004	15,000	6.080+5	4.806-3	72.59	21.64	3,990
0.373	244.0	3.45	0.554	0.1022	14,900	5.917+5	4.774-3	70.38	21.64	3,980
0.417	236.0	3.89	0.537	0.1048	14,700	5.745+5	4.725-3	68.15	21.64	3,980
0.461	226.9	4.39	0.515	0.1065	14,500	5.553+5	4.693-3	65.91	21.64	3,970
0.505	214.5	4.90	0.487	0.1091	14,200	5.340+5	4.645-3	63.64	21.64	3,970
0.551	200.9	5.48	0.458	0.1117	14,000	5.117+5	4.597-3	61.34	21.66	3,960
0.597	186.1	6.24	0.423	0.1152	13,700	4.874+5	4.533-3	59.01	21.66	3,950
0.645	166.8	6.92	0.381	0.1186	13,300	4.620+5	4.469-3	56.64	21.66	3,940
0.693	147.5	7.65	0.336	0.1221	12,900	4.357+5	4.405-3	54.24	21.69	3,930
0.744	127.1	8.50	0.290	0.1264	12,500	4.073+5	4.341-3	51.80	21.69	3,920
0.796	107.1	9.57	0.245	0.1316	12,100	3.850+5	4.309-3	49.83	21.71	3,900
0.850	87.6	10.68	0.202	0.1377	12,100	3.850+5	4.309-3	49.83	21.71	3,900
0.877	77.5	11.33	0.180	0.1403	12,100	3.850+5	4.309-3	49.83	21.71	3,900
0.919	123.7	10.65	0.286	0.1437	12,100	3.850+5	4.309-3	49.83	21.71	3,900
0.949	123.7	10.51	0.286	0.1463	12,100	3.850+5	4.309-3	49.83	21.71	3,900
0.978	122.6	10.46	0.285	0.1498	12,100	3.850+5	4.309-3	49.83	21.71	3,900
1.036	122.6	10.35	0.283	0.1559	12,100	3.850+5	4.309-3	49.83	21.71	3,900
1.153	121.4	10.12	0.281	0.1689	12,100	3.850+5	4.309-3	49.83	21.71	3,900
1.269	121.4	9.90	0.279	0.1810	12,100	3.850+5	4.309-3	49.83	21.71	3,900
1.386	120.3	9.68	0.277	0.1922	12,100	3.850+5	4.309-3	49.83	21.71	3,900
1.503	121.4	9.48	0.278	0.2044	12,100	3.850+5	4.309-3	49.83	21.71	3,910
1.619	122.6	9.25	0.281	0.2156	12,100	3.850+5	4.309-3	49.83	21.71	3,910
1.736	124.8	9.05	0.285	0.2295	12,100	3.850+5	4.309-3	49.83	21.71	3,910
1.852	127.1	8.83	0.291	0.2399	12,100	3.850+5	4.309-3	49.83	21.71	3,910
1.969	130.5	8.61	0.298	0.2511	12,100	3.850+5	4.309-3	49.83	21.71	3,910
2.086	133.9	8.38	0.305	0.2641	12,100	3.850+5	4.309-3	49.83	21.71	3,910
2.202	137.3	8.13	0.312	0.2762	12,100	3.850+5	4.309-3	49.83	21.71	3,910
2.319	139.6	7.87	0.319	0.2883	12,100	3.850+5	4.309-3	49.83	21.71	3,910

APPENDIX D

TABLE 3

Table a. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 47.2 sec

Orton cool-heavy model atmosphere
Nose radius $R_N = 0.352$ m
44.250 sphere cone shape

Freestream conditions
 $u_\infty = 46.55$ km/s
 $\rho_\infty = 9.45 \times 10^{-5}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\text{m}/\rho_\infty v_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance n_S/R_N	Temperature T_S , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K
0.000	106.1	0.17	0.910	0.0824	17,000	1.885+5	1.168-3	90.0	21.85	3,820
0.0965	108.6	0.57	0.974	0.0909	16,900	1.864+5	1.166-3	84.78	21.87	3,820
0.16073	108.6	0.88	0.972	0.0927	16,800	1.834+5	1.166-3	81.30	21.87	3,820
0.20115	107.6	1.08	0.969	0.0944	16,700	1.814+5	1.165-3	79.12	21.87	3,810
0.24182	106.2	1.27	0.957	0.0961	16,600	1.783+5	1.163-3	76.94	21.87	3,810
0.28281	104.3	1.49	0.941	0.0979	16,500	1.753+5	1.160-3	74.76	21.87	3,810
0.32419	101.9	1.69	0.917	0.0996	16,300	1.712+5	1.157-3	72.57	21.87	3,810
0.36604	98.7	1.88	0.890	0.1013	16,100	1.672+5	1.153-3	70.37	21.90	3,800
0.40845	95.2	2.09	0.856	0.1039	15,900	1.621+5	1.149-3	68.15	21.90	3,800
0.45146	91.1	2.30	0.818	0.1065	15,700	1.560+5	1.142-3	65.92	21.90	3,790
0.49515	86.7	2.52	0.776	0.1091	15,500	1.510+5	1.134-3	63.67	21.92	3,790
0.53964	81.7	2.77	0.730	0.1117	15,300	1.449+5	1.124-3	61.40	21.92	3,780
0.58505	76.5	3.02	0.680	0.1143	15,000	1.378+5	1.113-3	59.10	21.94	3,770
0.63155	70.8	3.25	0.626	0.1178	14,700	1.307+5	1.100-3	56.77	21.94	3,760
0.67929	65.0	3.44	0.572	0.1221	14,400	1.236+5	1.084-3	54.42	21.97	3,760
0.72837	58.8	3.63	0.512	0.1264	14,100	1.155+5	1.067-3	52.03	21.99	3,750
0.77906	52.6	3.84	0.453	0.1316	14,100	1.145+5	1.064-3	51.63	21.99	3,740
0.90249	64.7	4.02	0.575	0.1446	14,100	1.145+5	1.064-3	51.63	21.99	3,740
0.95826	65.7	3.89	0.583	0.1524	14,100	1.145+5	1.064-3	51.63	21.99	3,740
1.0142	67.1	3.71	0.594	0.1611	14,100	1.145+5	1.064-3	51.63	21.99	3,750
1.1256	70.0	3.34	0.619	0.1758	14,100	1.145+5	1.064-3	51.63	21.99	3,750
1.2371	72.4	3.03	0.640	0.1914	14,100	1.145+5	1.064-3	51.63	21.99	3,750
1.3487	74.6	2.77	0.659	0.2070	14,100	1.145+5	1.064-3	51.63	21.99	3,750
1.4601	76.7	2.55	0.678	0.2217	14,100	1.145+5	1.064-3	51.63	21.99	3,750
1.5716	78.9	2.37	0.697	0.3164	14,100	1.145+5	1.064-3	51.63	21.99	3,750
1.6831	81.0	2.20	0.717	0.2520	14,100	1.145+5	1.064-3	51.63	21.99	3,750
1.7946	83.1	2.07	0.736	0.2676	14,100	1.145+5	1.064-3	51.63	21.99	3,750
1.9061	85.0	1.94	0.754	0.2832	14,100	1.145+5	1.064-3	51.63	21.99	3,750
2.0177	86.8	1.83	0.771	0.2987	14,100	1.145+5	1.064-3	51.63	21.99	3,750
2.1292	88.5	1.74	0.787	0.3143	14,100	1.145+5	1.064-3	51.63	21.99	3,750
2.2408	90.0	1.65	0.801	0.3299	14,100	1.145+5	1.064-3	51.63	21.99	3,750

Table b. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 50.3 sec

Orton cool-heavy model atmosphere
Nose radius $R_N = 0.352$ m
44.250 sphere cone shape

Freestream conditions
 $u_\infty = 44.57$ km/s
 $\rho_\infty = 2.177 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\text{m}/\rho_\infty v_\infty$	Shock Layer Conditions						Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance n_S/R_N	Temperature T_S , K	Pressure P , N/m^2	Density ρ , kg/m^3	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K	
0.000	206.6	0.24	0.884	0.0883	17,300	3.952+5	2.531-3	90.0	21.71	3,930	
0.096	215.7	0.69	0.928	0.0944	17,300	3.921+5	2.531-3	84.82	21.71	3,920	
0.1600	217.9	0.99	0.932	0.0961	17,200	3.860+5	2.531-3	81.37	21.71	3,920	
0.2003	216.8	1.19	0.933	0.0970	17,100	3.810+5	2.515-3	79.21	21.71	3,920	
0.2409	215.6	1.38	0.931	0.0987	17,000	3.749+5	2.515-3	77.04	21.71	3,920	
0.2818	213.4	1.57	0.921	0.1004	16,800	3.678+5	2.515-3	74.88	21.71	3,920	
0.3231	208.8	1.74	0.904	0.1022	16,700	3.597+5	2.499-3	72.70	21.71	3,910	
0.3648	204.3	1.91	0.884	0.1039	16,500	3.506+5	2.483-3	70.52	21.71	3,910	
0.4071	199.7	2.07	0.863	0.1065	16,300	3.405+5	2.483-3	68.32	21.73	3,900	
0.4499	194.1	2.25	0.836	0.1082	16,100	3.293+5	2.467-3	66.10	21.73	3,900	
0.4935	186.2	2.45	0.803	0.1108	15,900	3.171+5	2.451-3	63.86	21.73	3,890	
0.5379	178.2	2.68	0.768	0.1143	15,600	3.050+5	2.419-3	61.60	21.73	3,890	
0.5832	169.1	2.94	0.729	0.1178	15,400	2.908+5	2.403-3	59.31	21.76	3,880	
0.6294	158.9	3.20	0.680	0.1212	15,100	2.756+5	2.371-3	56.99	21.76	3,870	
0.6769	147.5	3.45	0.631	0.1256	14,800	2.604+5	2.339-3	54.64	21.78	3,860	
0.7258	135.1	3.76	0.577	0.1308	14,400	2.452+5	2.291-3	52.26	21.78	3,850	
0.7761	121.4	4.10	0.518	0.1359	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
0.9005	156.6	4.12	0.673	0.1507	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
0.9282	155.5	3.97	0.671	0.1550	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
0.9559	155.5	3.87	0.669	0.1593	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
1.0115	155.5	3.67	0.669	0.1689	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
1.1223	157.8	3.30	0.673	0.1853	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
1.2332	158.9	3.0	0.678	0.2026	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
1.3440	158.9	2.74	0.680	0.2191	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
1.4547	160.0	2.50	0.682	0.2355	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
1.5655	161.2	2.32	0.688	0.2520	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
1.6762	163.4	2.18	0.694	0.2676	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
1.7868	165.7	2.05	0.704	0.2832	14,400	2.442+5	2.291-3	52.23	21.78	3,850	
1.8975	166.8	1.96	0.713	0.2987	14,400	2.442+5	2.291-3	52.23	21.80	3,850	
2.0081	169.1	1.87	0.722	0.3143	14,400	2.442+5	2.291-3	52.23	21.80	3,850	
2.1188	171.4	1.80	0.731	0.3299	14,400	2.442+5	2.291-3	52.23	21.80	3,850	
2.2294	173.6	1.74	0.740	0.3455	14,400	2.442+5	2.291-3	52.23	21.80	3,850	

Table c. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 52.1 sec

Orton cool-heavy model atmosphere
 Nose radius $R_N = 0.352$ m
 44.250 sphere cone shape

Freestream conditions
 $u_\infty = 42.50$ km/s
 $\rho_\infty = 3.478 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $m/\rho_\infty V_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance n_S/R_N	Temperature T_S , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_S	Enthalpy H_w , MJ/kg	Temperature T_w , K
0.000	273.5	0.30	0.781	0.0915	17,200	5.715+5	3.876-3	90.0	21.64	3,980
0.0957	281.5	0.83	0.805	0.0953	17,200	5.674+5	3.876-3	84.85	21.64	3,980
0.1597	282.6	1.19	0.808	0.0970	17,100	5.593+5	3.860-3	81.42	21.64	3,980
0.2000	282.6	1.41	0.810	0.0979	17,000	5.512+5	3.860-3	79.27	21.64	3,980
0.2406	281.5	1.63	0.806	0.0996	16,900	5.431+5	3.844-3	77.12	21.66	3,970
0.2815	279.2	1.87	0.802	0.1013	16,700	5.330+5	3.828-3	74.97	21.66	3,970
0.3227	275.8	2.09	0.793	0.1030	16,600	5.208+5	3.812-3	72.80	21.66	3,970
0.3644	270.1	2.28	0.778	0.1048	16,400	5.076+5	3.796-3	70.63	21.66	3,960
0.4066	263.3	2.47	0.758	0.1065	16,300	4.935+5	3.780-3	68.44	21.66	3,960
0.4094	255.4	2.69	0.734	0.1091	16,100	4.772+5	3.748-3	66.23	21.66	3,950
0.4929	247.4	2.92	0.710	1.1117	15,800	4.600+5	3.716-3	64.01	21.66	3,950
0.5372	237.2	3.18	0.681	0.1143	15,600	4.418+5	3.684-3	61.75	21.69	3,940
0.5824	227.0	3.48	0.652	0.1178	15,300	4.215+5	3.636-3	59.47	21.69	3,930
0.6286	213.4	3.81	0.612	0.1212	15,000	4.002+5	3.588-3	57.16	21.69	3,930
0.6760	199.7	4.12	0.571	0.1256	14,700	3.779+5	3.540-3	54.81	21.71	3,920
0.7247	183.9	4.49	0.526	0.1308	14,300	3.557+5	3.476-3	52.48	21.71	3,920
0.7750	166.8	4.91	0.475	0.1359	14,200	3.496+5	3.460-3	51.88	21.71	3,910
0.8977	206.6	4.95	0.596	0.1507	14,200	3.496+5	3.460-3	51.88	21.71	3,900
0.9255	205.4	4.77	0.592	0.1550	14,200	3.496+5	3.460-3	51.88	21.71	3,900
0.9534	204.3	4.65	0.588	0.1593	14,200	3.496+5	3.460-3	51.88	21.71	3,900
1.0091	203.2	4.44	0.583	0.1680	14,200	3.496+5	3.460-3	51.88	21.71	3,900
1.1204	202.0	4.06	0.579	0.1844	14,200	3.496+5	3.460-3	51.88	21.71	3,900
1.2315	202.0	3.76	0.576	0.2000	14,200	3.496+5	3.460-3	51.88	21.71	3,900
1.3427	202.0	3.48	0.576	0.2156	14,200	3.496+5	3.460-3	51.88	21.71	3,910
1.4540	202.0	3.26	0.577	0.2321	14,200	3.496+5	3.460-3	51.88	21.71	3,910
1.5650	204.3	3.06	0.582	0.2468	14,200	3.496+5	3.460-3	51.88	21.71	3,910
1.6762	206.6	2.92	0.587	0.2624	14,200	3.496+5	3.460-3	51.88	21.71	3,910
1.7873	208.8	2.78	0.594	0.2771	14,200	3.496+5	3.460-3	51.88	21.71	3,910
1.8984	211.1	2.67	0.601	0.2927	14,200	3.496+5	3.460-3	51.88	21.71	3,910
2.0095	213.4	2.55	0.608	0.3074	14,200	3.496+5	3.460-3	51.88	21.71	3,910
2.1206	215.6	2.46	0.615	0.3230	14,200	3.496+5	3.460-3	51.88	21.71	3,910
2.2317	217.9	2.38	0.621	0.3377	14,200	3.496+5	3.460-3	51.88	21.71	3,910

Table d. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 53.00 sec

Orton cool-heavy model atmosphere
 Nose radius $R_N = 0.352$ m
 44.250 sphere cone shape

Freestream conditions
 $u = 41.16$ km/s
 $\rho_\infty = 4.362 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance S_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\dot{m}/\rho_\infty v_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance η_S/R_N	Temperature T_S , K	Pressure P , N/m^2	Density ρ , kg/m^3	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K
0.000	301.9	0.39	0.712	0.0926	17,100	6.708+5	4.741-3	90.0	21.62	4,000
0.0956	309.8	0.93	0.733	0.0961	17,000	6.657+5	4.741-3	84.87	21.62	4,000
0.15964	311.0	1.34	0.735	0.0979	16,900	6.556+5	4.725-3	81.45	21.64	4,000
0.1999	309.8	1.59	0.735	0.0987	16,800	6.475+5	4.709-3	79.31	21.64	4,000
0.2404	308.7	1.85	0.733	0.1004	16,700	6.373+5	4.693-3	77.17	21.64	4,000
0.2813	306.4	2.13	0.728	0.1013	16,600	6.257+5	4.677-3	75.02	21.64	3,990
0.3225	301.9	2.36	0.717	0.1030	16,400	6.120+5	4.661-3	72.86	21.64	3,990
0.3642	296.2	2.58	0.706	0.1048	16,300	5.958+5	4.629-3	70.70	21.64	3,990
0.4064	290.5	2.79	0.691	0.1074	16,100	5.796+5	4.597-3	68.52	21.64	3,980
0.4492	282.6	3.04	0.672	0.1091	15,900	5.603+5	4.565-3	66.31	21.64	3,980
0.4927	272.4	3.31	0.648	0.1117	15,700	5.401+5	4.533-3	64.09	21.64	3,970
0.5369	262.2	3.63	0.624	0.1143	15,400	5.188+5	4.485-3	61.84	21.66	3,960
0.5821	249.6	4.02	0.595	0.1178	15,200	4.955+5	4.437-3	59.56	21.66	3,960
0.6282	237.2	4.35	0.563	0.1212	14,900	4.701+5	4.373-3	57.25	21.66	3,950
0.6756	220.2	4.72	0.524	0.1256	14,500	4.448+5	4.309-3	54.91	21.66	3,940
0.7243	204.3	5.20	0.483	0.1308	14,200	4.175+5	4.229-3	52.54	21.69	3,930
0.7744	182.7	5.64	0.432	0.1359	14,100	4.104+5	4.213-3	51.94	21.69	3,930
0.8966	228.1	5.65	0.543	0.1498	14,100	4.104+5	4.213-3	51.94	21.69	3,930
0.9245	225.8	5.46	0.540	0.1541	14,100	4.104+5	4.213-3	51.94	21.69	3,930
0.9523	224.7	5.33	0.535	0.1585	14,100	4.104+5	4.213-3	51.94	21.69	3,930
1.008	222.4	5.10	0.528	0.1671	14,100	4.104+5	4.213-3	51.94	21.69	3,930
1.1191	220.2	4.69	0.521	0.1827	14,100	4.104+5	4.213-3	51.94	21.69	3,930
1.2301	217.9	4.37	0.517	0.1983	14,100	4.104+5	4.213-3	51.94	21.69	3,930
1.3412	216.8	4.10	0.513	0.2139	14,100	4.104+5	4.213-3	51.94	21.69	3,930
1.4521	216.8	3.85	0.513	0.2286	14,100	4.104+5	4.213-3	51.94	21.69	3,930
1.5631	219.0	3.65	0.516	0.2433	14,100	4.104+5	4.213-3	51.94	21.69	3,930
1.6740	221.3	3.48	0.521	0.2580	14,100	4.104+5	4.213-3	51.94	21.69	3,930
1.7850	223.6	3.34	0.527	0.2728	14,100	4.104+5	4.213-3	51.94	21.69	3,930
1.8960	227.0	3.20	0.534	0.2875	14,100	4.104+5	4.213-3	51.94	21.69	3,930
2.0069	229.3	3.09	0.540	0.3022	14,100	4.104+5	4.213-3	51.94	21.69	3,930
2.1179	231.5	2.98	0.546	0.3169	14,100	4.104+5	4.213-3	51.94	21.69	3,930
2.2288	233.8	2.88	0.552	0.3316	14,100	4.104+5	4.213-3	51.94	21.69	3,930

Table e. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 54.1 sec

Orton cool-heavy model atmosphere
Nose radius $R_N = 0.352$ m
44.250 sphere cone shape

Freestream conditions
 $U_\infty = 39.22$ km/s
 $\rho_\infty = 5.699 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\dot{m}/\rho_\infty V_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance n_S/R_N	Temperature T_S , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K
0.000	328.0	0.30	0.624	0.0939	16,700	7.934+5	5.975-3	90.0	21.62	4,030
0.0956	334.8	0.61	0.637	0.0970	16,700	7.863+5	5.975-3	84.9	21.62	4,030
0.1596	337.1	0.94	0.640	0.0987	16,600	7.751+5	5.959-3	81.5	21.62	4,030
0.1998	335.9	1.16	0.641	0.0996	16,500	7.650+5	5.943-3	79.37	21.62	4,020
0.2403	334.8	1.40	0.639	0.1004	16,400	7.539+5	5.911-3	77.24	21.62	4,020
0.2811	331.4	1.63	0.635	0.1022	16,300	7.397+5	5.895-3	75.10	21.62	4,020
0.3223	326.8	1.90	0.627	0.1039	16,100	7.235+5	5.863-3	72.96	21.62	4,020
0.3640	321.2	2.11	0.615	0.1056	16,000	7.052+5	5.831-3	70.80	21.62	4,010
0.4061	313.2	2.32	0.600	0.1074	15,800	6.850+5	5.783-3	68.63	21.62	4,010
0.4489	305.3	2.52	0.584	0.1100	15,600	6.637+5	5.735-3	66.43	21.62	4,000
0.4923	293.9	2.76	0.561	0.1126	15,400	6.394+5	5.687-3	64.22	21.64	4,000
0.5365	281.5	3.01	0.538	0.1152	15,100	6.140+5	5.622-3	61.98	21.64	3,990
0.5816	267.8	3.30	0.511	0.1178	14,800	5.867+5	5.558-3	59.70	21.64	3,980
0.6277	250.8	3.62	0.479	0.1221	14,500	5.573+5	5.478-3	57.40	21.64	3,970
0.6748	231.5	3.90	0.441	0.1256	14,200	5.269+5	5.398-3	55.07	21.64	3,970
0.7234	212.2	4.22	0.402	0.1308	13,800	4.955+5	5.318-3	52.70	21.66	3,960
0.7735	189.5	4.63	0.359	0.1359	13,700	4.864+5	5.286-3	52.04	21.66	3,950
0.8953	242.9	4.83	0.464	0.1498	13,700	4.864+5	5.286-3	52.04	21.66	3,950
0.9231	241.7	4.76	0.462	0.1541	13,700	4.864+5	5.286-3	52.04	21.66	3,950
0.9509	239.5	4.71	0.458	0.1585	13,700	4.864+5	5.286-3	52.04	21.66	3,950
1.0063	236.1	4.60	0.451	0.1663	13,700	4.864+5	5.286-3	52.04	21.66	3,950
1.1171	232.7	4.36	0.444	0.1810	13,700	4.864+5	5.286-3	52.04	21.66	3,950
1.2279	230.4	4.18	0.438	0.1957	13,700	4.864+5	5.286-3	52.04	21.66	3,950
1.3387	229.3	4.02	0.435	0.2104	13,700	4.864+5	5.286-3	52.04	21.66	3,950
1.4494	228.1	3.87	0.433	0.2243	13,700	4.864+5	5.286-3	52.04	21.66	3,950
1.5601	229.3	3.72	0.436	0.2381	13,700	4.864+5	5.286-3	52.04	21.66	3,950
1.6708	231.5	3.60	0.440	0.2520	13,700	4.864+5	5.286-3	52.04	21.66	3,950
1.7816	234.9	3.48	0.445	0.2667	13,700	4.864+5	5.286-3	52.04	21.66	3,950
1.8923	237.2	3.38	0.451	0.2806	13,700	4.864+5	5.286-3	52.04	21.66	3,950
2.0030	240.6	3.29	0.457	0.2944	13,700	4.864+5	5.286-3	52.04	21.66	3,950
2.1137	244.0	3.20	0.462	0.3083	13,700	4.864+5	5.286-3	52.04	21.66	3,950
2.2245	246.3	3.12	0.468	0.3230	13,700	4.864+5	5.286-3	52.04	21.66	3,950

Table f. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 56.3 sec

Orton cool-heavy model atmosphere
Nose radius $R_N = 0.352$ m
44.250 sphere cone shape

Freestream conditions
 $u_\infty = 34.42$ km/s
 $\rho_\infty = 9.353 \times 10^{-4}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\dot{m}/\rho_\infty v_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance η_S/R_N	Temperature T_S , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K
0.000	307.6	0.37	0.404	0.0962	15,500	9.920+5	8.954-3	90.0	21.59	4,060
0.0955	317.8	0.84	0.419	0.0987	15,500	9.849+5	8.922-3	85.0	21.59	4,060
0.1595	320.0	1.34	0.423	0.0996	15,400	9.707+5	8.890-3	81.67	21.59	4,060
0.1998	318.9	1.66	0.422	0.1004	15,300	9.585+5	8.874-3	79.58	21.59	4,060
0.2403	316.6	1.98	0.419	0.1013	15,200	9.443+5	8.843-3	77.49	21.59	4,060
0.2811	313.2	2.29	0.414	0.1030	15,100	9.271+5	8.794-3	75.39	21.59	4,050
0.3223	306.4	2.63	0.407	0.1039	14,900	9.079+5	8.746-3	73.28	21.59	4,050
0.3639	299.6	3.00	0.397	0.1056	14,800	8.856+5	8.698-3	71.15	21.59	4,050
0.406	290.5	3.41	0.385	0.1074	14,600	8.613+5	8.634-3	69.01	21.59	4,040
0.4487	278.0	3.77	0.369	0.1091	14,400	8.339+5	8.554-3	66.85	21.59	4,040
0.4920	264.4	4.14	0.350	0.1117	14,100	8.055+5	8.474-3	64.67	21.59	4,040
0.5361	247.4	4.55	0.329	0.1143	13,900	7.741+5	8.394-3	62.45	21.59	4,020
0.5810	229.3	5.06	0.304	0.1169	13,600	7.407+5	8.314-3	60.20	21.62	4,020
0.6268	210.0	5.66	0.278	0.1195	13,200	7.052+5	8.217-3	57.92	21.62	4,010
0.6738	187.3	6.37	0.247	0.1230	12,800	6.677+5	8.121-3	55.60	21.62	4,000
0.7220	162.3	7.29	0.215	0.1264	12,400	6.282+5	8.041-3	53.25	21.62	3,980
0.7718	137.3	8.58	0.182	0.1308	11,800	5.887+5	7.977-3	50.86	21.62	3,970
0.8232	111.9	10.28	0.150	0.1351	11,500	5.694+5	7.961-3	49.74	21.64	3,960
0.9138	133.9	9.56	0.180	0.1446	11,500	5.694+5	7.961-3	49.74	21.64	3,960
0.9423	133.9	9.37	0.178	0.1472	11,500	5.694+5	7.961-3	49.74	21.64	3,960
0.9993	131.7	9.17	0.176	0.1524	11,500	5.694+5	7.961-3	49.74	21.64	3,960
1.1132	129.4	9.09	0.173	0.1628	11,500	5.694+5	7.961-3	49.74	21.64	3,960
1.2272	127.1	9.09	0.169	0.1732	11,500	5.694+5	7.961-3	49.74	21.64	3,960
1.3411	124.8	9.10	0.166	0.1836	11,500	5.694+5	7.961-3	49.74	21.64	3,960
1.4551	122.6	9.12	0.163	0.1940	11,500	5.694+5	7.961-3	49.74	21.64	3,960
1.5690	122.6	9.08	0.163	0.2044	11,500	5.694+5	7.961-3	49.74	21.64	3,960
1.6830	122.6	9.00	0.163	0.2147	11,500	5.694+5	7.961-3	49.74	21.64	3,960
1.7969	123.7	8.87	0.165	0.2251	11,500	5.694+5	7.961-3	49.74	21.64	3,960
1.9109	126.0	8.73	0.167	0.2355	11,500	5.694+5	7.961-3	49.74	21.64	3,960
2.0249	128.2	8.57	0.170	0.2468	11,500	5.694+5	7.961-3	49.74	21.64	3,960
2.1388	131.7	8.41	0.174	0.2572	11,500	5.694+5	7.961-3	49.74	21.64	3,960
2.2530	135.1	8.24	0.179	0.2693	11,500	5.694+5	7.961-3	49.74	21.64	3,960

Table g. Fully Coupled Turbulent Flow Around the Body

RASLE Solutions for Entry Time = 58.5 sec

Orton cool-heavy model atmosphere
Nose radius $R_N = 0.352$ m
44,250 sphere cone shape

Freestream conditions
 $u_\infty = 28.81$ km/s
 $\rho_\infty = 1.439 \times 10^{-3}$ kg/m³

Normalized Streamwise Distance s_{body}/R_N	Heating Rate MW/m^2		Normalized Ablation Rate $\dot{m}/\rho_\infty v_\infty$	Shock Layer Conditions					Wall Conditions	
	Radiative q_R	Convective q_C		Normalized Standoff Distance η_S/R_N	Temperature T_S , K	Pressure P , N/m ²	Density ρ , kg/m ³	Shock Angle θ_S	Enthalpy H_W , MJ/kg	Temperature T_W , K
0.000	175.9	0.56	0.173	0.1001	13,300	1.054+6	1.232-2	90.00	21.59	4,030
0.0953	204.3	1.87	0.205	0.1030	13,300	1.044+6	1.230-2	85.17	21.59	4,070
0.1592	204.3	3.06	0.206	0.1039	13,200	1.034+6	1.227-2	81.95	21.59	4,070
0.1993	200.9	3.94	0.203	0.1048	13,100	1.023+6	1.224-2	79.93	21.57	4,060
0.2397	194.1	4.90	0.198	0.1056	13,000	1.007+6	1.222-2	77.90	21.57	4,060
0.2804	185.0	5.99	0.189	0.1065	12,800	9.910+5	1.219-2	75.87	21.57	4,060
0.3214	173.6	7.27	0.179	0.1074	12,700	9.707+5	1.216-2	73.82	21.57	4,050
0.3629	161.2	8.85	0.167	0.1082	12,500	9.494+5	1.213-2	71.76	21.57	4,040
0.4048	147.5	10.84	0.154	0.1100	12,200	9.251+5	1.209-2	69.68	21.59	4,030
0.4473	131.7	13.39	0.140	0.1108	12,000	8.988+5	1.208-2	67.57	21.59	4,020
0.4905	114.6	16.34	0.125	0.1126	11,700	8.704+5	1.208-2	65.44	21.62	4,010
0.5344	96.92	19.63	0.110	0.1143	11,300	8.390+5	1.211-2	63.27	21.66	3,990
0.5791	79.56	23.27	0.0948	0.1152	10,800	8.065+5	1.217-2	61.06	21.73	3,970
0.6248	63.21	27.12	0.0813	0.1169	10,300	7.721+5	1.233-2	58.82	21.83	3,950
0.6716	48.46	30.98	0.0698	0.1186	9,630	7.366+5	1.261-2	56.35	21.97	3,930
0.7196	35.86	34.27	0.0599	0.1186	8,840	6.991+5	1.309-2	54.21	22.01	3,910
0.7692	25.76	36.77	0.0519	0.1204	7,920	6.617+5	1.386-2	51.85	22.15	3,880
0.8206	17.93	38.47	0.0456	0.1212	6,940	6.231+5	1.496-2	49.45	22.31	3,850
0.8470	14.64	39.15	0.0428	0.1212	6,470	6.029+5	1.559-2	48.24	22.38	3,840
0.9035	9.79	39.61	0.0382	0.1195	5,800	5.684+5	1.666-2	46.20	22.48	3,820
0.9335	9.51	39.49	0.0383	0.1204	5,800	5.684+5	1.666-2	46.20	22.50	3,820
0.9935	9.06	39.38	0.0377	0.1212	5,800	5.684+5	1.666-2	46.20	22.55	3,810
1.1135	8.38	39.27	0.0370	0.1247	5,800	5.684+5	1.666-2	46.20	22.64	3,790
1.2335	7.81	39.38	0.0364	0.1282	5,800	5.684+5	1.666-2	46.20	22.73	3,780
1.3535	7.26	39.49	0.0361	0.1325	5,800	5.684+5	1.666-2	46.20	22.80	3,770
1.4736	6.70	39.61	0.0357	0.1359	5,800	5.684+5	1.666-2	46.20	22.90	3,760
1.5936	6.08	39.83	0.0353	0.1403	5,800	5.684+5	1.666-2	46.20	22.97	3,740
1.7137	5.40	39.95	0.0348	0.1455	5,800	5.684+5	1.666-2	46.20	23.01	3,730
1.8337	4.71	40.29	0.0344	0.1507	5,800	5.684+5	1.666-2	46.20	23.08	3,720
1.9538	4.11	40.52	0.0342	0.1559	5,800	5.684+5	1.666-2	46.20	23.13	3,710
2.0739	3.64	40.97	0.0342	0.1611	5,800	5.684+5	1.666-2	46.20	23.17	3,700
2.1940	3.33	41.65	0.0345	0.1671	5,800	5.684+5	1.666-2	46.20	23.22	3,700
2.3141	3.16	42.33	0.0351	0.1732	5,800	5.684+5	1.666-2	46.20	23.24	3,690